Applied Thermal Dynamics			
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Lab# 1-9	LabVolt Manual		
Professor:	Martin Gram		
Student Name:	Family SINGH	First IAN	
Student #	N 01057429		
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HUMBER

Refrigeration and HVAC

Refrigeration Systems and Controls

Student Manual

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Internet: www.festo-didactic.com
e-mail: did@de.festo.com

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Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
⎓	Direct current
∿	Alternating current
≂	Both direct and alternating current
3∿	Three-phase alternating current
⏚	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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About This Manual

The accelerated demand for refrigeration and air-conditioning applications has increased the need for a greater number of practical, technical and sales personnel who have a thorough understanding of the various refrigeration systems and controls.

Refrigeration Systems and Controls has been prepared to provide the student with a thorough understanding of theory and operation of various types of control devices and systems. Troubleshooting skills will also be developed through a number of controlled faults incorporated into the system.

This manual is organized in a unit/exercise format with clearly-stated behavioral objectives for each unit and each exercise contained within a unit. Each unit includes a Unit Objective, background Discussion material, New-Word identification and definition and a listing of the materials necessary to conduct the various exercises contained in the unit. Each exercise within a unit includes an Exercise Objective, Discussion material, step-by-step Procedure, Conclusion and essay-type Review Questions. Units are concluded with an objective-type Unit Test. The training manual also contains various supporting appendices such as Mechanical and Electrical Service Analysis, Troubleshooting Flowcharts, Pressure/Temperature (P/T) Chart of Refrigerants, Conversion Factors, Glossary of Terms and Bibliography.

The material presented in this manual is intended to create a practical sense of good judgment and a level of refrigeration and air-conditioning knowledge that will enable you to enter the more specialized areas of study in the field of refrigeration and air-conditioning.

The answers to all procedural questions, review questions, and unit test questions are provided in the Instructor Guide *Refrigeration Systems and Controls*.

It is very important to keep in mind that the numerical results given in the Instructor Guide for the procedural questions are given as guidelines only. In fact, these results may differ somewhat from those obtained by the student, because they are dependent upon the ambient (room) temperature, the amount of refrigerant charge within the trainer, etc.

The important thing is for students to observe and understand the principles involved, the reasons why the system behaves in a certain way under specific conditions, and the general trends of the system parameters, that is, the manner in which two or more variables change in relation to each other, such as the pressures and temperatures at various points of the system.

Also, it is important, when performing temperature measurements, that the sensing elements of the temperature probes be placed firmly against the tubing. The better the thermal contact between the sensing elements of the probes and the tubing, the better the accuracy of measurements. An accuracy of measurement of ± 1.1°C (± 2°F) is expected. When a temperature measurement seems erroneous, it is recommended to double-check the measurement by connecting another probe near the sensing location to see if both probes provide similar temperature readings. Or, another digital temperature meter can be used to check the accuracy of measurement of the trainer temperature probes.

About This Manual

Also note that the condenser and evaporator fan speed settings given in each exercise should be used as a starting point, and could require readjustments if the pressures and temperatures measured in the exercise, or the expected system behavior seem erroneous.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by the units expressed in the U.S. customary system of units (between parentheses).

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

Unit 1

Introduction to the Refrigeration System Trainer

UNIT OBJECTIVE

Upon completion of this unit, you will be familiar with, and be able to identify, the main panels on the Refrigeration System Trainer.

DISCUSSION OUTLINE

The Discussion of Fundamentals covers the following points:

- New terms and words
- Equipment required

DISCUSSION OF FUNDAMENTALS

The Refrigeration System Trainer consists of two control panels and a refrigeration system panel.

The control panel contains the necessary control, monitoring and protective equipment to enable the trainee to investigate various refrigeration principles and perform practical exercises on many refrigeration system configurations.

The system panel contains the necessary devices, such as manual valves, liquid receiver and **suction accumulator**, required to configure many refrigeration systems.

The complete system trainer is represented on a **schematic** panel. This panel shows the electrical and tubing schematics for the trainer. The schematics are complete with indicator lamps and testing points.

New terms and words

Celsius – the scale of changes of temperature which uses 0°C (32°F) as the freezing point and 100°C (212°F) as the boiling point for water at standard pressure.

Condenser – the device in a refrigeration system where refrigerant gives off the heat which was absorbed at the evaporator.

Evaporator – the refrigerant filled device in the low pressure side of a refrigeration system which absorbs the unwanted heat from the area to be cooled.

Pressure – force on a unit area exerted by the molecules of refrigerant (varies directly with absolute temperature).

Refrigeration – the process of removing heat under controlled conditions.

Schematic – a diagram showing the layout of a system, using symbols to represent the various components.

Solenoid valve – electromagnet with a moving core which serves as a stem to operate a valve.

Suction accumulator – storage tank which receives liquid refrigerant from the evaporator and prevents it from flowing into the suction line of the compressor before vaporizing.

Equipment required

- Refrigeration System Trainer, Model 3401

System Control Panels

Exercise Objective

When you have completed this exercise, you will be familiar with the operation of the system panel by configuring a typical refrigeration system following schematic and pictorial diagrams.

Discussion Outline

The Discussion of this exercise covers the following points:

- Introduction

Discussion

Introduction

The Refrigeration System Trainer is equipped with two control panels and a schematic panel. These panels are used to monitor and control the operations required for refrigeration training. The main control panel, mounted on the left side of the system trainer, is shown in Figure 1-1. This panel contains three meters: an ac voltmeter (M1); an ac ammeter (M2); and a wattmeter (M3). These meters are used to monitor the electrical system of the trainer. The meters are wired into the system as shown on the schematic panel, Figure 1-3.

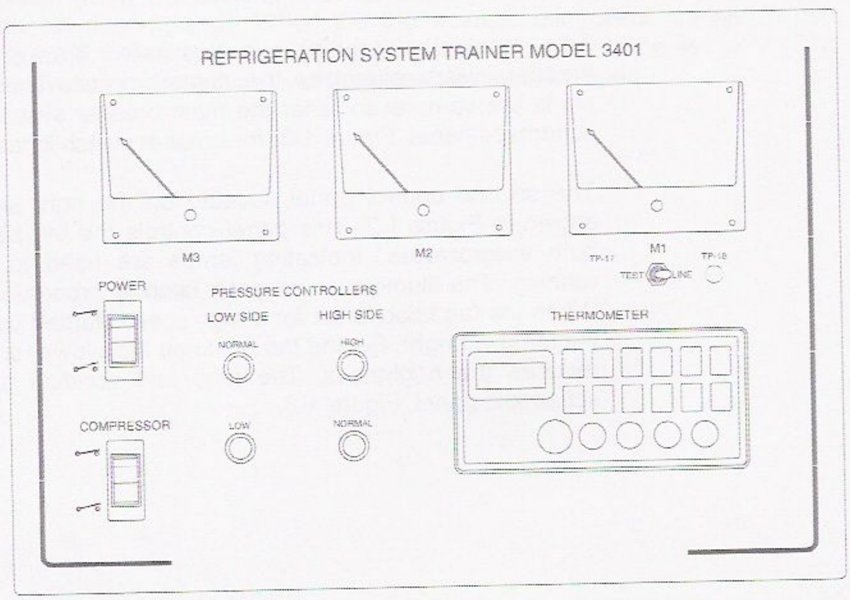


Figure 1-1. The main control panel.

The ac voltmeter (M1) is used to monitor the system voltage, or as a test meter for troubleshooting. Selecting "TEST", using the selector switch, removes the meter from the line. The meter can then be used to measure specific voltages, for troubleshooting purposes, at test points (TP) located on the schematic panel.

A digital thermometer is also included on this panel. It permits temperature measurements at four different locations, in either Celsius or Fahrenheit degrees.

The temperature readings can be stored to a memory with battery back-up. The temperature differential between two points can be measured at the press of one button. The meter comes with a set of sensing probes:

- General purpose probes can be used to measure temperature within the evaporator's cabinet, or at various points of the system tubing, in which case they must be secured firmly against the tubing with the supplied "velcro" strips to ensure a good thermal contact between their sensing element and the tubing.

- If your set of probes includes clamp-on probes, these probes can be used to measure temperature all along the system tubing. It is particularly recommended that you use these probes for temperature measurements at the evaporator's inlet and outlet to ensure a good accuracy of measurement.

- Finally, if your set of probes includes an air (coiled) probe, this probe can be used to measure temperature within the evaporator's cabinet.

Indicator lamps are mounted on the panel to show the condition of the pressure controllers. When a pressure controller, either high or low, is in normal operation, a green indicator lamp is illuminated. If either controller experiences an abnormal condition, a yellow lamp is illuminated. These lamps are also found on the electrical schematic panel. The pressure controllers are located in the system, as shown on the tubing schematic.

This panel also includes two illuminated breaker switches. The mains input breaker switch energizes the control circuit. The compressor breaker switch starts the compressor after the main breaker switch is turned on. See electrical schematic panel, Figure 1-3, for breaker switch location.

The second control panel, located on the right side of the system trainer, is shown in Figure 1-2. This panel controls the fan speed for the **condenser** and both **evaporators**. Indicating lamps are used to indicate when each fan is running. The illumination of each lamp is proportional to the speed of the fan. When the fan knob is set for a high speed (turned counterclockwise near "OFF"), the lamp is bright. Setting the fan knob for a lower speed (knob turned clockwise) reduces the brightness. The fans and controls are shown on the electrical schematic panel, Figure 1-3.

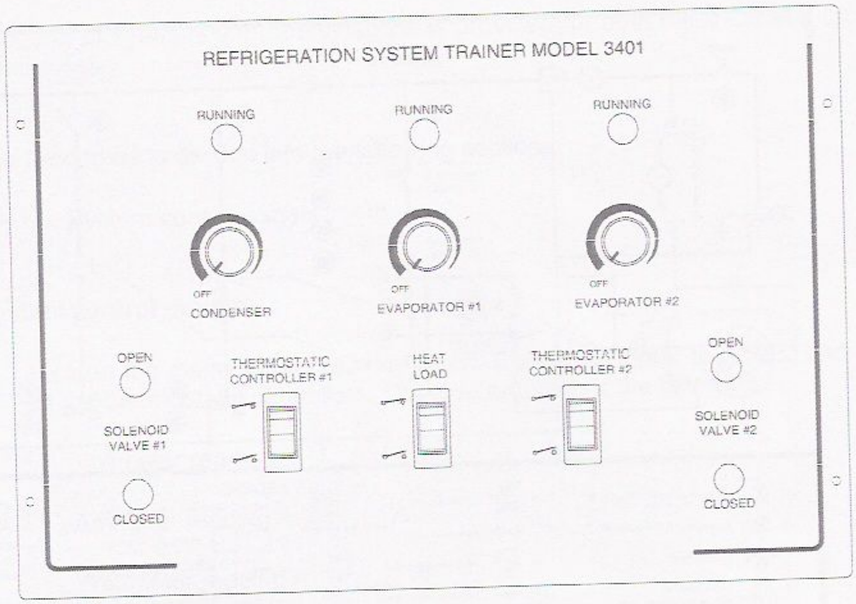


Figure 1-2. The second control panel.

This panel also controls the operation of two thermostatic controllers, TIC1 and TIC2. Illuminated breaker switches are used to energize two solenoid valves through the thermostatic controllers. These are connected as shown on the electrical schematic panel in Figure 1-3. The devices are placed in the system as shown on the tubing schematic panel in Figure 1-3. Illuminated lamps are used to indicate when the solenoid valves are open (solenoid energized) or closed (solenoid deenergized). When the thermostatic controllers are not in use, the "BYPASS" switch on the electrical schematic panel must be set to "I" (ON) and the manual bypass valves over the solenoids must be open.

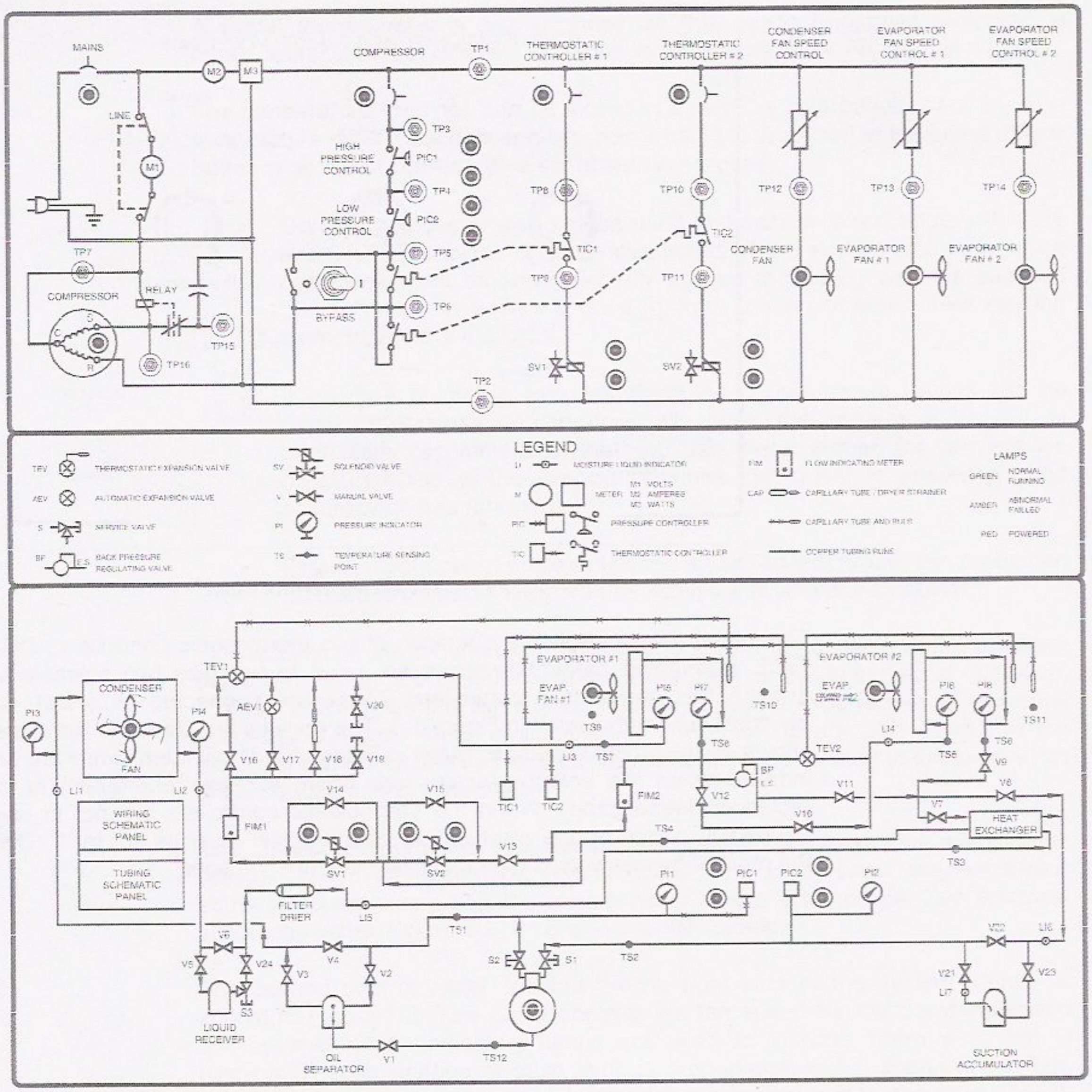


Figure 1-3. The schematic (electrical and tubing) panel.

The schematic panel, as shown in Figure 1-3, is located on the left hand side of the system trainer, directly above the main control panel. This panel shows the electrical and tubing schematics of the system trainer.

The electrical schematic identifies the monitoring and control devices found on the system and control panels. Test points are located on this panel for troubleshooting using the schematic panel.

The tubing schematic identifies the control valves, monitoring devices and control devices found on the system panel. All devices on the tubing schematic are labeled as shown in the legend of symbols. Temperature sensor points are also included on this panel to indicate the most practical point for temperature measurement.

A legend of symbols and abbreviations is provided for both electrical and tubing schematics.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- System control panels

PROCEDURE

System control panels

1. Turn on the mains input breaker switch. Switch voltmeter to "LINE" and turn off the thermostatic controllers. Observe and record the following:

   Voltmeter reading = 110 V ac

   Ammeter reading = 0 A

   Wattmeter reading = 0 W

   Low side pressure = 468 kPa or 68 psi

   High side pressure = 483 kPa or 70 psi

2. Turn on the condenser fan and evaporator-1 fan. Vary the speed of these fans. Record observations of the fan's behavior.

   Higher condensor speed, more energy and heat rejection

3. Adjust the following manual valves as indicated below (refer to Figure 1-4):

VALVES OPENED			VALVES CLOSED		
V1	V8	V14	V4	V13	V19
V2	V9	V18	V5	V15	V20
V3	V11	V21	V7	V16	V22
V6	V12	V23	V10	V17	V24

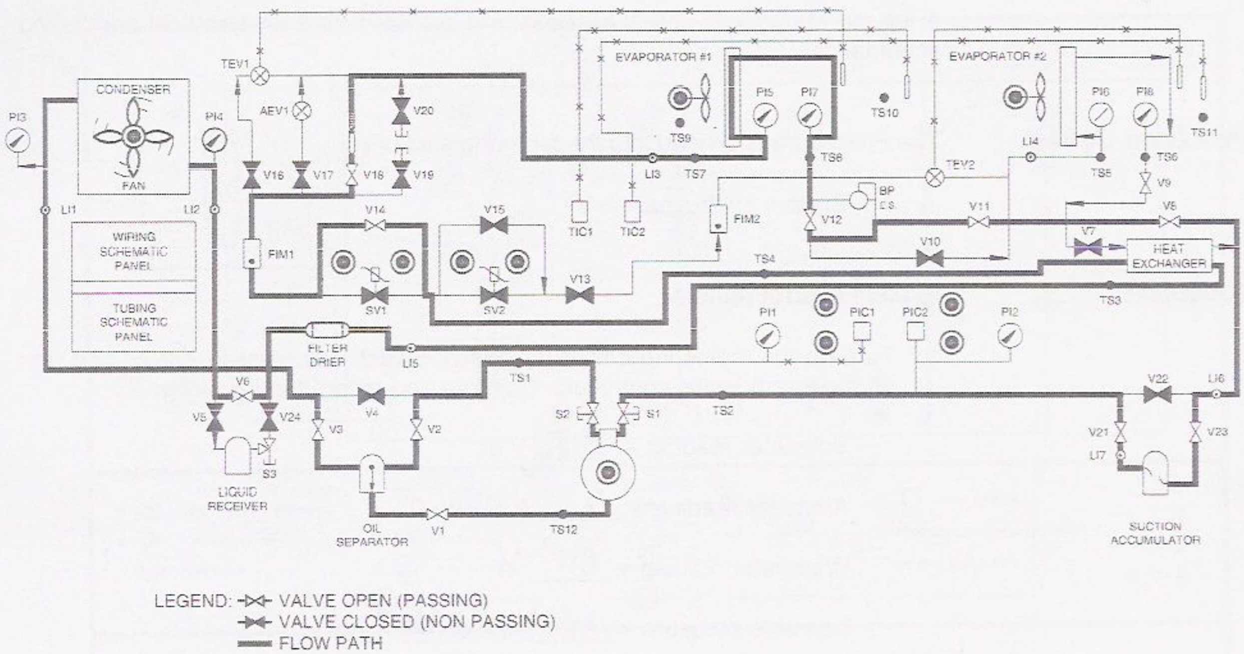


Figure 1-4. Valve configuration.

4. Have valves checked by instructor.

   Set the condenser fan speed to **medium**, and the evaporator-1 fan speed to **medium**.

   The condenser and evaporator fan speed settings are given here as guidelines only, and could require readjustments if the pressures and temperatures measured in this exercise seem erroneous. For a room temperature of 21°C (70°F), and with no load applied on the system, a low-side pressure of around 100-140 kPa (15-20 psi) and a high-side pressure of around 860-1035 kPa (125-150 psi) indicate normal system operation.

5. Turn on the compressor breaker switch. Observe and record the following:

   Voltmeter reading = 110 V ac

   Ammeter reading = 7 A

   Wattmeter reading = 490 W

   Low side pressure = 199.9 kPa or 29 psi

   High side pressure = 965 kPa or 140 psi

   In this exercise and for the rest of the manual, immediately turn off the compressor if the ammeter needle goes beyond the maximum of the meter scale, then advise your instructor. Excessive current drawn upon compressor start-up will occur when, for example, an excessive pressure differential is present across the suction and discharge sides of the compressor, or if liquid refrigerant has entered the compressor.

Did the compressor data change? Explain.

YES, THE DATA CHANGED BECAUSE THE COMPRESSOR WAS RUNNING, HIGH SIDE PRESSURE INCREASED, LOW SIDE DECREASED, AMPS AND WATTAGE INCREASED

6. Switch the ac voltmeter to "TEST".

7. Connect leads to the voltmeter (TP-17, 18) on the main control panel.

8. Measure and record the voltage between test points TP1 and TP2 on the schematic panel (electrical section).

   $V_{TP1,\ TP2}$ = 110 V ac

⚠ WARNING

Do not short test leads or touch metal tips of test leads as high voltages are being measured.

9. Connect one of the thermometer probes to input A of this meter. Turn on the thermometer. Press button A of this meter.

10. With the probe, measure and record the temperatures at TS1 and TS2. The temperature test point locations are shown on the schematic panel (tubing section) in Figure 1-3.

    If you are using a general purpose probe to measure the temperatures, make sure to secure it firmly against the tubing with the supplied "velcro" strips to ensure a good thermal contact between its sensing element and the tubing.

    TS1 = 33.1 °C or 91.6 °F

    TS2 = -1.5 °C or 29.3 °F

    Turn off the meter.

    Compare temperatures TS1 and TS2 to the ambient (room) temperature and record your observations.

    Ambient: 25°c

    THE TS1 IS LOWER (LOW SIDE) AND TS2 IS HIGHER THAN AMBIENT TEMPERATURE

11. Have your results checked by the instructor.

12. Turn off the compressor breaker switch and then the mains input breaker switch.

Conclusion

The refrigeration system trainer has two control panels to monitor and control the system. The voltmeter on the main control panel is used to monitor the system voltage, or as a test meter. Indicator lamps are used to indicate pressure controller and fan speed conditions. An analog temperature meter monitors specific temperatures in the system.

The schematic panel shows the electrical and tubing schematics of the system trainer. The schematics are complete with indicator lamps, test points, temperature sensor points and appropriate schematic symbols.

Review Questions

1. What is the voltmeter used for and where is it located?

   TO MEASURE VOLTAGE AS WELL AS TO TEST THE VOLTAGE AT VARIOUS POINTS IN THE SYSTEM

2. What is the digital thermometer used for and where is it located?

   TO MEASURE TEMPERATURE IN CABINET AS WELL AS AT DIFFERENT TEST POINTS

3. List some of the thermometer functions.

   - MEASURE TEMPERATURE
   - MEASURE TEMP DIFFERENCE BETWEEN TWO POINTS
   - MEASURE HUMIDITY + DEW POINT
   - MEASURE WET-BULB + DRY BULB TEMPERATURE

4. How can you approximately determine the evaporator fan speed?

   LOOK AT RATING PLATE, FULL SPEED WILL BE 100% OF THE RATING, HALF SPEED WILL BE HALFWAY BETWEEN HIGHEST AND LOWEST SETTING ON THE CONTROL DIAL.

5. Explain the function of the schematic panel.

TO DETERMINE LOCATION OF COMPONENTS, VALVES AND TEST POINTS AS WELL AS TO ~~S~~ SHOW THE SEQUENCE OF OPERATION

System Configuration

EXERCISE OBJECTIVE When you have completed this exercise, you will be able to configure a typical refrigeration system following schematic and pictorial diagrams.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Introduction

DISCUSSION

Introduction

The Refrigeration System Trainer is shown in Figure 1-5. All necessary devices required to learn the principles of different refrigeration systems are mounted on this panel. Each device can be added to, or removed from, the basic refrigeration system by opening or closing the appropriate manual valve. These devices are all identified on the schematic panel (tubing section), using symbols shown in the legend. This panel also has test points (TP) and temperature sensor points (TS) indicating the location of the voltage and temperature measurement points throughout the system.

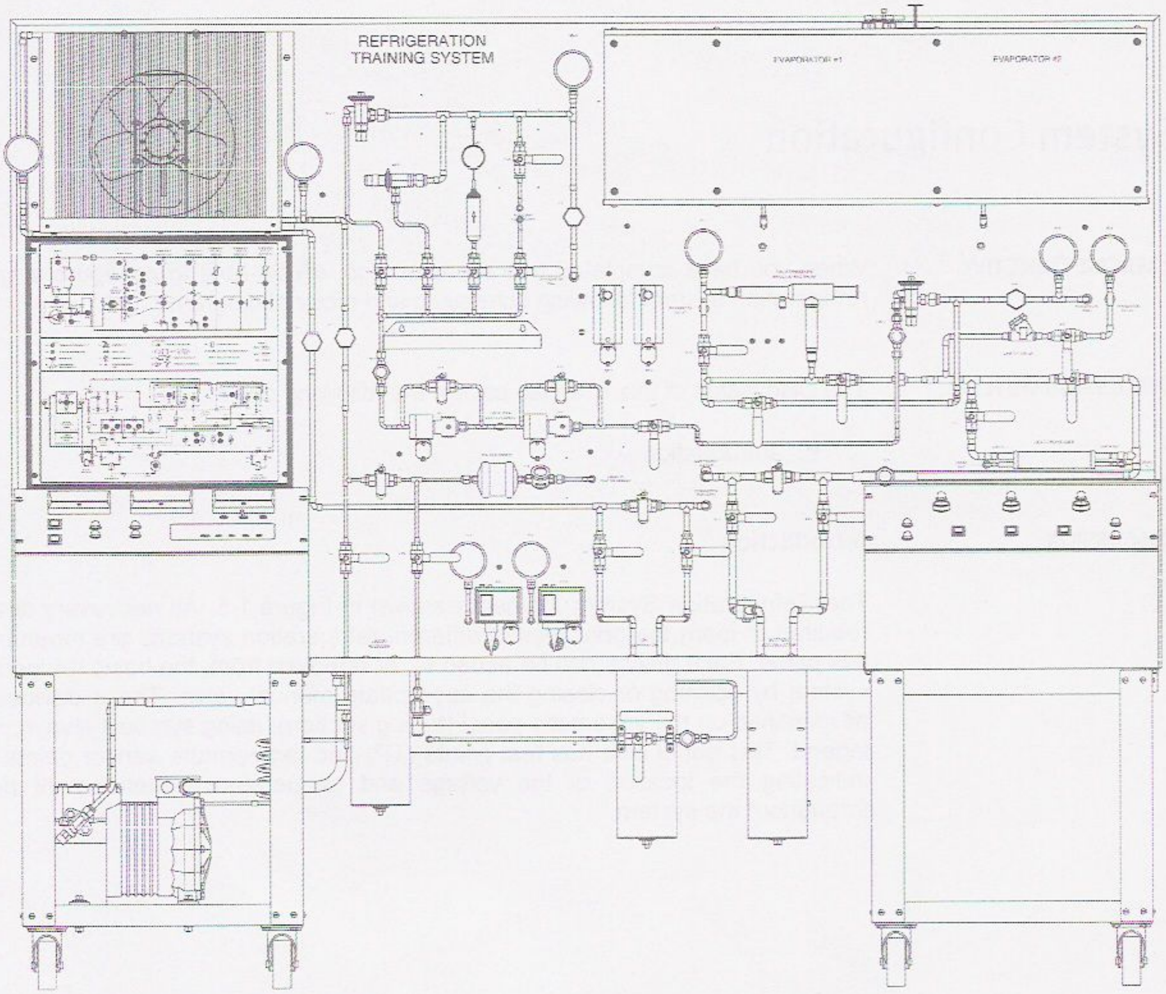


Figure 1-5. Refrigeration System Trainer.

To connect a refrigeration system, a tubing schematic diagram, as shown in Figure 1-6, is required. This diagram shows the devices required to connect the system and their locations within the system. This diagram does not show which manual valves should be opened or closed. It is therefore necessary for you to understand how to follow this diagram.

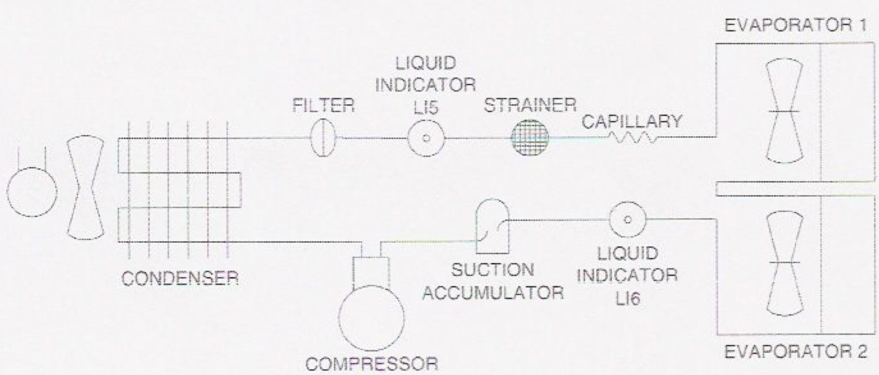


Figure 1-6. Tubing schematic panel.

The schematic panel (tubing section) on the trainer (Figure 1-7) identifies the valves which must be closed to set up the refrigeration system shown in Figure 1-6. The valves that are darkened in Figure 1-7 must be closed and the valves that are white must be open. Follow through the schematic panel in Figure 1-7 with the schematic diagram in Figure 1-6.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- System configuration

PROCEDURE

System configuration

1. Compare the tubing schematic diagram of Figure 1-6 with the schematic panel (tubing section) on the trainer.

2. Observe all devices, test points, and temperature sensor points. Which test points are used to check the condenser fan?

   TP12 AND TP2 ARE USED TO CHECK CONDENSER FAN FOR VOLTAGE.

3. The following is a list of the trainer's manual valves which must be opened and closed to form the system shown in Figure 1-6.

VALVES OPENED				VALVES CLOSED			
V4	V10	V21		V1	V7	V16	V22
V6	V12	V23		V2	V11	V17	V24
V8	V14			V3	V13	V19	
V9	V18			V5	V15	V20	

Follow through the schematics in Figure 1-6 and Figure 1-7 as you open and close the valves.

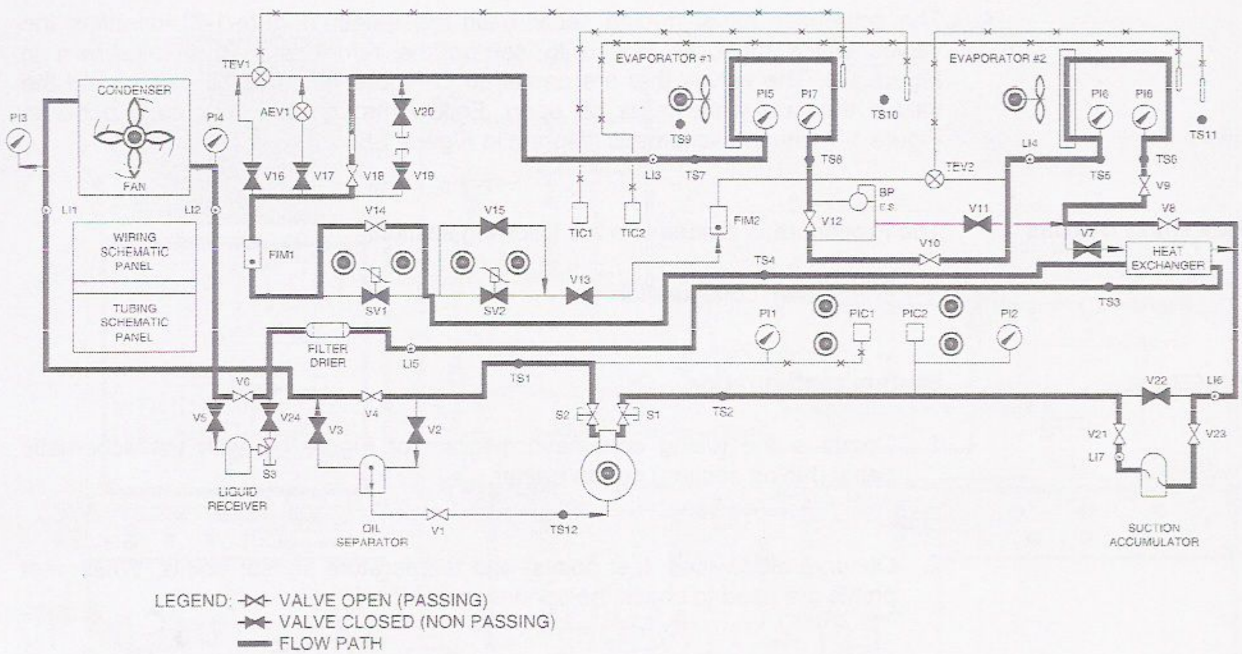


Figure 1-7. Valve configuration.

4. List the valves that must be opened and closed to add the following device to the system of Figure 1-7: liquid receiver and oil separator.

Valves opened

1. V5
2. V24
3. V3
4. V2
5. V1

Valves closed

1. V6
2. V4

5. Have your results checked by the instructor.

CONCLUSION

The trainer's schematic panel (electrical and tubing sections) indicates the devices required to form many refrigeration systems. The devices are added to, or removed from, the system by opening or closing appropriate manual valves.

REVIEW QUESTIONS

1. On Figure 1-7, which manual valve is used to allow/block the flow of refrigerant to the capillary tube control? Is this valve shown as open or closed in the figure?

   V18 IS USED TO BLOCK THE FLOW OF REFRIGERANT

2. When the voltmeter is on "TEST", which test points are used to measure the supply voltage to the electrical control circuit?

   TP 17

3. Which temperature sensing (TS) point is used to measure the compressor suction temperature?

   TS2 MEASURES SUCTION TEMPERATURE

Unit Test

1. The main control panel on the trainer contains

   a. system devices.
   b. electrical and tubing schematic diagrams.
   c. monitoring and control devices.
   d. temperature and electrical test points.

2. The voltmeter on the trainer

   a. monitors the line voltage.
   b. is used as a test meter.
   c. is used when troubleshooting the trainer.
   d. All the above are correct.

3. When the yellow indicator lamp for the high pressure control is illuminated, the system

   a. is operating correctly.
   b. pressure is too low.
   c. pressure is too high.
   d. safety switch is activated.

4. When the condenser fan control knob is turned completely clockwise, the fan is on

   a. high and the indicator lamp is bright.
   b. high and the indicator lamp is dull.
   c. low and the indicator lamp is dull.
   d. low and the indicator lamp is bright.

5. The schematic panel on the trainer provides

   a. the electrical schematic of the trainer.
   b. the tubing schematic of the trainer.
   c. test points for troubleshooting the trainer.
   d. All the above are correct.

6. The capillary tube control and the liquid receiver are mounted on the

   a. schematic panel.
   b. system panel.
   c. main control panel.
   d. fan control panel.

7. A tubing schematic diagram shows

   a. the valves to be opened and closed.
   b. the devices to be used in a system.
   c. the physical location of the devices in a system.
   d. All the above are correct.

Receivers, Accumulators, Oil Separators

UNIT OBJECTIVE

Upon completion of this unit, you will be familiar with the operation of liquid receivers, suction accumulators and oil separators by observing the effects of each when placed in a refrigeration system.

DISCUSSION OUTLINE

The Discussion of Fundamentals covers the following points:

- New terms and words
- Equipment required

DISCUSSION OF FUNDAMENTALS

Liquid receivers are commonly used on refrigeration systems with **expansion valve** refrigerant control. The receiver is usually placed in the system after the condenser to collect the liquid refrigerant, ensuring a constant supply of refrigerant liquid to the expansion device. This also eliminates the need for a precise charge on the system.

Suction accumulators are used on refrigeration systems that are subject to sudden liquid return such as in heat pump systems. The accumulator is placed in the system just before the compressor to collect the liquid refrigerant, preventing it from flowing to the compressor.

Oil separators are used in refrigeration systems to collect the oil that may have been pumped from the compressor crankcase by the compressor and into the system's lines. The separator is placed just after the compressor to collect the oil that may be mixed with the refrigerant vapor. The oil collects in the tank and can be returned to the compressor either manually or automatically.

New terms and words

Capillary – a tube with a very small inside diameter; its diameter and length control the flow of the refrigerant between the high- and low-pressure sides of the refrigeration system.

Expansion valve – a temperature control valve which maintains constant superheat in the evaporator and operates on increased pressure, resulting from temperature rise at a certain point in the system.

Hermetic – used to describe a compressing unit which is sealed air tight by welding together of the outer casing.

Float valve – a liquid level control which opens or closes a valve when the liquid level rises.

Oil separator – a device on the high-pressure side of a refrigeration system which removes oil from the refrigerant.

Sight glass (or liquid indicator) – a clear glass window which allows observation of liquid refrigerant level or the presence of bubbles in the lines.

Suction line – the tubing run through which heat laden refrigerant vapor travels from the evaporator to the compressor.

Equipment required

- Refrigeration System Trainer, Model 3401

Exercise 2-1

Liquid Receiver

EXERCISE OBJECTIVE When you have completed this exercise, you will be able to explain the principles of a liquid receiver, by adding one to a simple refrigeration system.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Introduction

DISCUSSION

Introduction

A liquid receiver, as shown in Figure 2-1, is used as a storage tank for liquid refrigerant. When a liquid receiver is used in a refrigeration system, the refrigerant is usually pumped out of the various devices and stored in it during servicing.

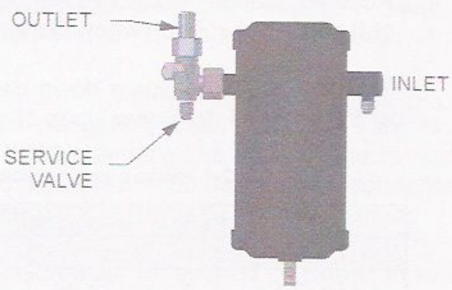


Figure 2-1. Liquid receiver.

Liquid receivers are commonly used on refrigeration systems with expansion valve refrigerant control. Receivers are not used on systems with a capillary tube since all the liquid refrigerant is stored in the evaporator. With the increased use of capillary tubes in hermetic systems, the need for liquid receivers has diminished in domestic systems and in many small commercial units.

Receivers are mounted either vertically or horizontally, as shown in Figure 2-2. The horizontal type usually hangs underneath the compressor and motor frame or the condenser. Receivers are usually equipped with one or two service valves. One liquid receiver service valve is mounted between the liquid receiver and the condenser. The other is placed between the receiver and the liquid line.

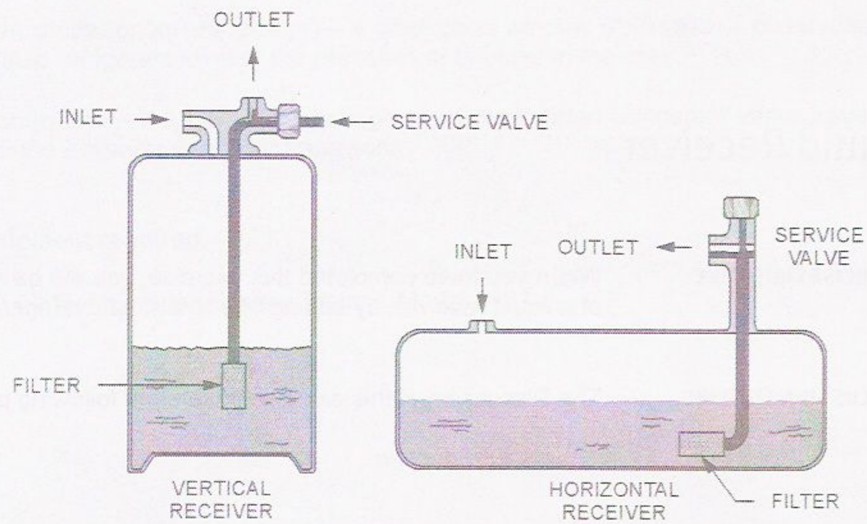


Figure 2-2. Vertical and horizontal liquid receivers.

A fine copper screen on the outlet prevents dirt from entering the refrigerant control devices. Some receivers are equipped with a **sight glass** or float for determining the level of liquid refrigerant.

Receiver storage capacities are based on the liquid occupying no more than 90% of the internal volume when the temperature of the refrigerant is 32°C (90°F).

Table 2-1 lists the pump down capacities calculated at 90% of receiver volume at 32°C (90°F), for some types of refrigerants.

Table 2-1. Pump down capacities at 90% of receiver volume at 32°C (90°F).

Pump down capacity			Connections	
R-134a	**R-22**	**R-404a/R-507**	**Inlet**	**Outlet**
1.1 kg (2.4 lb)	1.1 kg (2.4 lb)	0.9 kg (2.0 lb)	6.35 mm (0.25 in) flare	6.35 mm (0.25 in) flare
1.5 kg (3.3 lb)	1.5 kg (3.3 lb)	1.3 kg (2.8 lb)		
3.0 kg (6.7 lb)	3.0 kg (6.6 lb)	2.6 kg (5.7 lb)		
8.0 kg (17.6 lb)	7.8 kg (17.3 lb)	6.8 kg (15.0 lb)	9.525 mm (0.375 in) flare	12.7 mm (0.5 in) flare
13.3 kg (29.4 lb)	13.2 kg (29.1 lb)	11.4 kg (25.2 lb)	15.875 mm (0.625 in) flare	15.875 mm (0.625 in) flare

A schematic diagram of a simple refrigeration system using a liquid receiver is shown in Figure 2-3. Each device in this schematic is appropriately labeled.

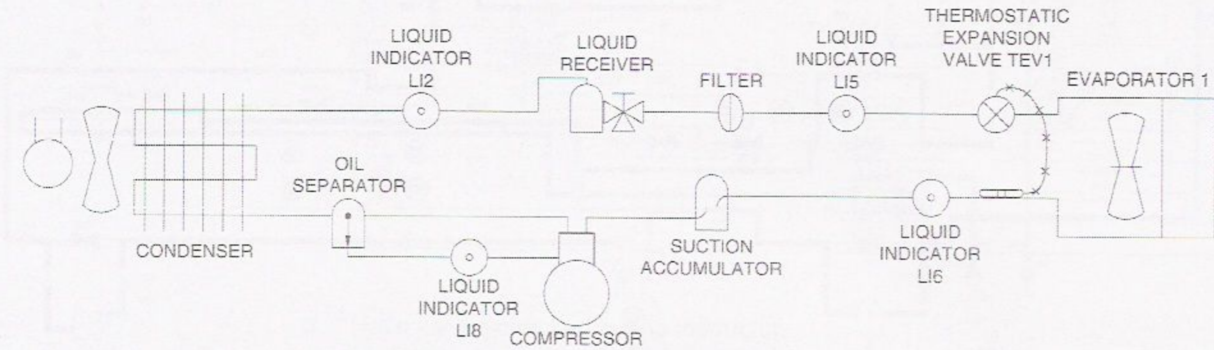
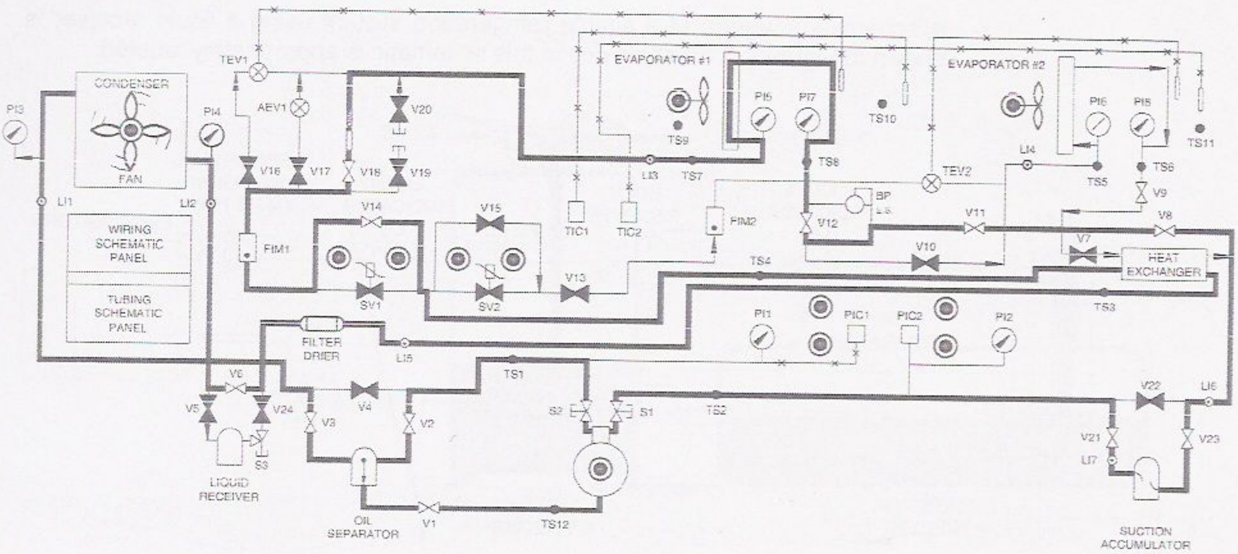


Figure 2-3. Refrigeration system using a liquid receiver.

High pressure refrigerant vapor flows from the compressor to the condenser where heat is removed from the refrigerant, changing the vapor to a liquid/vapor combination. The refrigerant flows from the condenser through the liquid indicator LI2 to the liquid receiver. The receiver collects the liquid refrigerant in the bottom of the receiver and discharges a constant supply of liquid to the filter drier and thermostatic expansion device. This allows the charge of refrigerant to be less critical.

A low pressure liquid refrigerant flows from the TEV to the evaporator. The evaporator absorbs heat, changing the state of the refrigerant from liquid to a vapor. The vaporized refrigerant then flows to the condenser. The cycle repeats until the desired temperature is reached.

The manual valves which must be opened or closed to arrange this system are not indicated on this schematic. However, a pictorial diagram of the system panel, shown in Figure 2-4, indicates the open and closed manual valves. The valves that are darkened are closed. A pictorial diagram is not used in the field since it requires too much time to draw and is therefore not practical. It is therefore necessary for you to become familiar with the schematic diagram as soon as possible.



LEGEND: VALVE OPEN (PASSING)
VALVE CLOSED (NON PASSING)
FLOW PATH

Figure 2-4. Valve configuration.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Liquid receiver

PROCEDURE

Liquid receiver

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 2-3. The trainer's schematic panel (tubing section) shown in Figure 2-4 may be used to assist at this point.

   Follow through the schematic diagram as you open and close each valve.

   Also, place the evaporator cabinet divider (located at the top of the two evaporator cabinet) in the up position in order to isolate evaporator 1 from evaporator 2. (A sliding bolt mechanism is used to lock the cabinet divider into place).

   The cabinet divider provides a means of isolating one evaporator cabinet from the other. In the down position, the divider allows air flow to pass from evaporator 1 into evaporator 2 (in that case, the evaporators are in series, so that evaporator 1 pre-cooling of the air before entering evaporator 2). In the up position, the divider isolates the air flow for each evaporator (in that case, the evaporators are in parallel, so that each evaporator is operated independent of the other).

2. Record which valves are open and closed by completing the remainder of the list below.

OPEN VALVES			CLOSED VALVES		
V1	V14		V4	V18	
V2	~~V16~~		V6	V20	
V3	V21		V7	V22	
V5	V23		V10	~~V14~~	
V8	V16		V13	V9	
~~V9~~	V24		V15		
V11			~~V16~~		
V12			V17		

3. Have valves checked by the instructor.

4. Turn on the mains input breaker switch.

5. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to maximum.

> *The condenser and evaporator fan speed settings are given here as guidelines only, and could require readjustments if the system does not behave as expected or described in the steps that follow. For a room temperature of 21°C (70°F), and with no load applied on the system, a low side pressure of around 100-140 kPa (15-20 psi) and a high side pressure of around 860-1035 kPa (125-150 psi) indicate normal system operation once the system is stable.*

6. Turn on the compressor breaker switch to start up the system.

7. Allow the system to operate for approximately 10 minutes. This will stabilize the system.

8. Observe the liquid indicator LI2. Is liquid flowing in the line going to the liquid receiver? Explain.

Yes there is a saturated mixture going to the liquid receiver

9. Observe the liquid indicator FIM1. Are bubbles present in the line going to the thermostatic expansion valve (TEV1)?

   No bubbles present

10. Slowly close valve V24 on the liquid receiver. After approximately one minute, slowly close valve V5 and slowly open valve V6. This will hold some of the refrigerant in the liquid receiver to simulate an undercharged system.

11. Allow the system to stabilize for approximately 5 minutes.

12. Observe the liquid indicator FIM1 again. Is a vapor-liquid mixture present in the line going to TEV1? Explain.

   No, there's no liquid or bubbles in FIM1, which indicates only vapor is present in this portion of the line

13. Turn off the condenser and evaporator fans.

14. Turn off the compressor and main breaker switch.

Conclusion

Liquid receivers are used as a storage tank for refrigerant when servicing the system. This enables the quantity of refrigerant in a system to be less critical. Liquid receivers are usually used on refrigeration systems with expansion valve refrigerant control. Receivers are mounted either vertically or horizontally.

Review Questions

1. Why do liquid receivers allow the quantity of refrigerant in a system to be less critical?

   They allow excess refrigerant to be stored and not overwhelm the expansion Valve

2. Can liquid receivers be used on refrigeration systems which use a capillary tube? Explain.

   No. Capillary tube systems store all refrigerant in evaporator

3. Where are receivers installed in a refrigeration system?

   To store excess liquid refrigerant, after the condenser.

4. What is the pump down capacity, calculated at 90% of receiver volume, for R-134a refrigerant at 32°C (90°F), for inlet and outlet connections of 6.35 mm (0.25 in) flare (refer to Table 2-1).

   2.4 – 6.6 lb

5. On most commercial systems, how much larger in volume should the liquid receiver be than the volume of the entire system?

   It should be 80 % larger than the volume of the system

Exercise 2-2

Suction Line Accumulator

EXERCISE OBJECTIVE When you have completed this exercise, you will be able to explain the principles of a suction line accumulator by observing the effects of one in a simple refrigeration system.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Introduction

DISCUSSION

Introduction

A suction line accumulator, also called a suction accumulator, shown in Figure 2-5, is a safety device used to prevent liquid refrigerant from flowing into the suction line and into the compressor. Compressors used in many air conditioning, heat pump and other refrigeration systems are often subjected to sudden liquid return. This could result in broken valves, pistons, connecting rods and blown gaskets to the compressor. However, if a suction line accumulator is installed and liquid refrigerant suddenly returns through the suction line, the refrigerant is temporarily held in the suction line accumulator. The refrigerant is then metered back to the compressor at a controlled rate through the metering orifice.

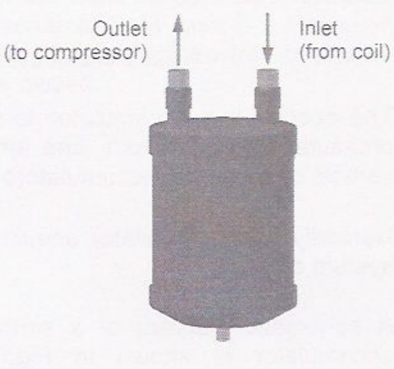


Figure 2-5. Suction line accumulator.

The suction line accumulator should be installed in the suction line as close to the compressor as possible. On heat pump systems, it must be installed in the suction line between the compressor and reversing valve.

It is very important that the inlet and outlet of the suction line accumulator be correctly connected to prevent oil and refrigerant from becoming trapped. The inlet should be connected to the suction line from the coil and the outlet to the suction line leading to the compressor. When liquid refrigerant enters the suction line accumulator, it falls to the bottom of the accumulator. The refrigerant is then metered back to the compressor through the small metering hole as shown in

Figure 2-6. A fusible plug is located on the side of the receiver. This is a safety device which will blow out on a high suction temperature or pressure. The plug has a small hole through its center and is filled with solder. When the temperature increases too much, and other safety devices fail, the solder will melt and release the pressure in the accumulator.

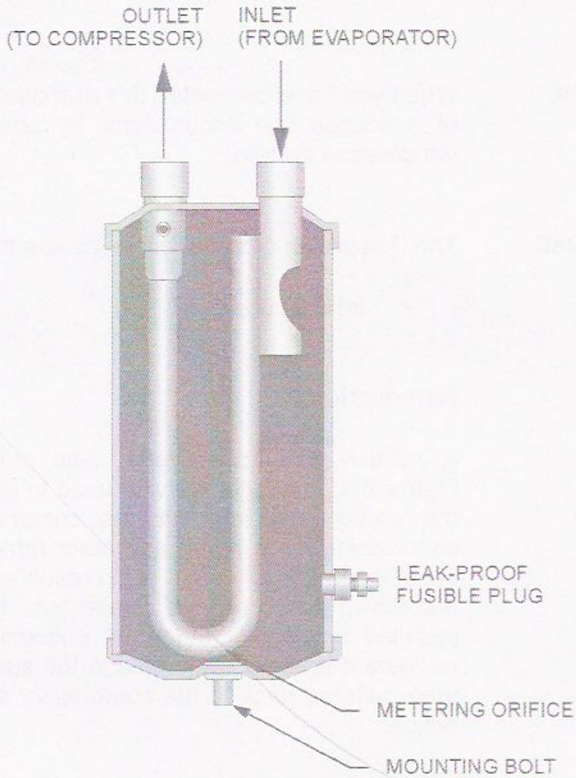


Figure 2-6. Cross section of a suction line accumulator.

The suction line accumulator to be used should be sized within the limits of pressure drop, oil return, and amount of charge. Diameter, length, and either vertical or horizontal accumulators are also important.

Normally the accumulator should not be sized for less than 50% of the total system capacity.

A schematic diagram of a simple refrigeration system using a suction line accumulator is shown in Figure 2-7. Each device in this schematic is appropriately labeled.

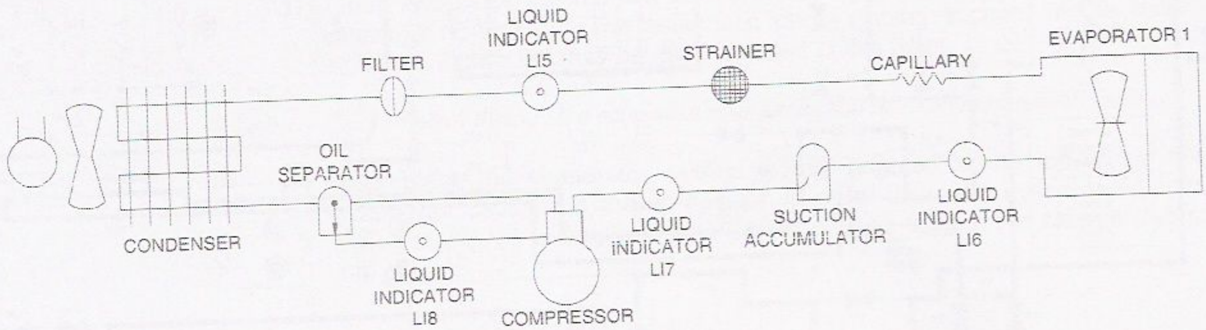


Figure 2-7. Refrigeration system using a suction line accumulator.

High pressure refrigerant vapor flows from the compressor to the condenser where heat is removed from the refrigerant. The refrigerant condenses into liquid and then flows from the condenser through the capillary tube. After exiting the capillary tube, the refrigerant becomes a low pressure liquid refrigerant which flows through the evaporator where heat is absorbed, changing the state of the refrigerant to a vapor. However some liquid usually remains in the line. A suction accumulator is therefore installed in the suction line to collect the liquid refrigerant before it enters the compressor. The refrigerant enters the suction line accumulator where the liquid refrigerant is separated from the refrigerant vapor. Liquid refrigerant is then metered back to the compressor at a controlled rate through a metering hole. This ensures a constant supply of refrigerant vapor to the compressor, eliminating the possibility of damage to the compressor.

The manual valves which must be opened or closed to arrange this system are not indicated on the schematic of Figure 2-7. However, they are indicated on the schematic panel (tubing section) of the trainer shown in Figure 2-8. The valves that are darkened are closed.

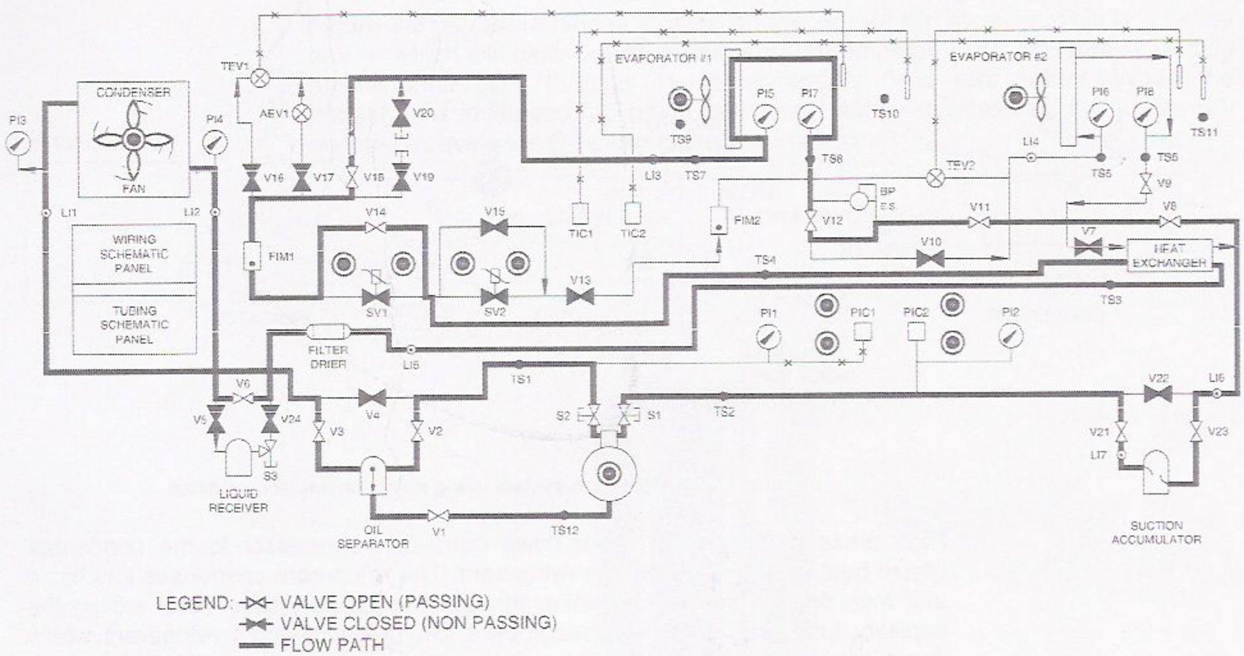


Figure 2-8. Valve configuration.

A diagram such as that screened on the trainer is not always used in the field since it requires too much time to draw and is therefore not practical. It is therefore necessary for you to become familiar with this diagram as soon as possible.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Suction line accumulators

PROCEDURE

Suction line accumulators

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 2-7. The schematic panel (tubing section) of the trainer shown in Figure 2-8 may be used to assist at this point.

   Follow through the schematic diagram as you open and close each valve.

   Also, place the evaporator cabinet divider (located at the top of the two evaporator cabinet) in the up position in order to isolate evaporator 1 from evaporator 2. (A sliding bolt mechanism is used to lock the cabinet divider into place).

2. Record which valves are opened and closed.

OPEN VALVES			CLOSED VALVES		
V1	V18		V4	V19	
V2	V21		V5	V20	
V3	V23		V7	V22	
V8	V6		V10	V24	
~~[illegible]~~			V13	V9	
V11			V15		
V12			V16		
V14			V17		

3. Have valves checked by the instructor.

4. Turn on the main input breaker.

5. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to medium.

6. Turn on the compressor breaker switch to start up the system.

7. Close valve V6 and open valve V24. Allow the system to operate for approximately 60 seconds. Close valve V24 and open valve V6. This removes most of the refrigerant from the liquid receiver, ensuring a charged system.

   While valves V6 and V5 are both closed, the low-side pressure decreases rapidly, which might cause the low pressure controller to shut off the compressor. In that case, most of the liquid refrigerant has been removed from the receiver so valve V24 can be closed and valve V6 can be opened to make the compressor restarts.

8. Allow the system to operate for approximately 5 minutes. This will stabilize the system.

9. In a properly charged (or over-charged) system, liquid refrigerant may pass through the evaporator without being vaporized and will be seen within liquid indicator LI6.

   Observe liquid indicator LI6. What do you observe?

   There's liquid in the glass (and therefore the suction line)

   If liquid refrigerant is seen within LI6, can this be a potential problem to the operation of the refrigeration system if the suction line accumulator is absent from the compressor suction line?

   Yes, the compressor can be damaged if too much liquid is allowed in it

10. Observe liquid indicator LI7. Do you see liquid within it? Why?

    Yes, but far less than LI6, the accumulator absorbs most of the liquid present and allows minute quantities back into the line

11. Turn off the condenser and evaporator fans.

12. Turn off the compressor and mains breaker switch.

Conclusion

Suction line accumulators are safety devices which prevent liquid refrigerant from flowing into the suction line and into the compressor. This device is used on refrigeration systems that are subject to sudden liquid return such as in heat pump systems. Suction line accumulators are installed on the suction side of the system as close to the compressor as possible.

Review Questions

1. What is a suction line accumulator?

   A device installed in the suction line between the evaporator and ~~[illegible]~~ compressor that prevents liquid refrigerant from going to the compressor

2. Explain what happens to the accumulator when liquid refrigerant suddenly returns through the suction line?

   The accumulator makes liquid refrigerant fall to the bottom of accumulator where it's safely metered back to the compressor in vapor form.

3. Where is the suction line accumulator installed on a heat pump system?

   Between the compressor and the reversing valve.

4. What is the inlet and outlet of the suction line accumulator connected to?

   Inlet is connected to the evaporator side of suction line, outlet connected to the compressor side of the suction line.

5. What factors are involved when determining which accumulator should be used?

   System size, pressure drop, oil return and system charge are factors to consider

Impinging, helical

Oil Separator

Exercise Objective

When you have completed this exercise, you will be able to explain the principles of an oil separator by adding one to a simple refrigeration system.

Discussion Outline

The Discussion of this exercise covers the following points:

- Introduction

Discussion

Introduction

When a compressor operates, a small amount of oil is pumped out along with the hot compressed vapor. Small amounts of oil within the system are not harmful. However, if too much oil is permitted to enter the system, devices such as the condenser, evaporator, filters and refrigerant control devices are affected. This will greatly reduce the efficiency of the system. To avoid this situation, an oil separator, as shown in Figure 2-9, is placed between the compressor outlet and the condenser.

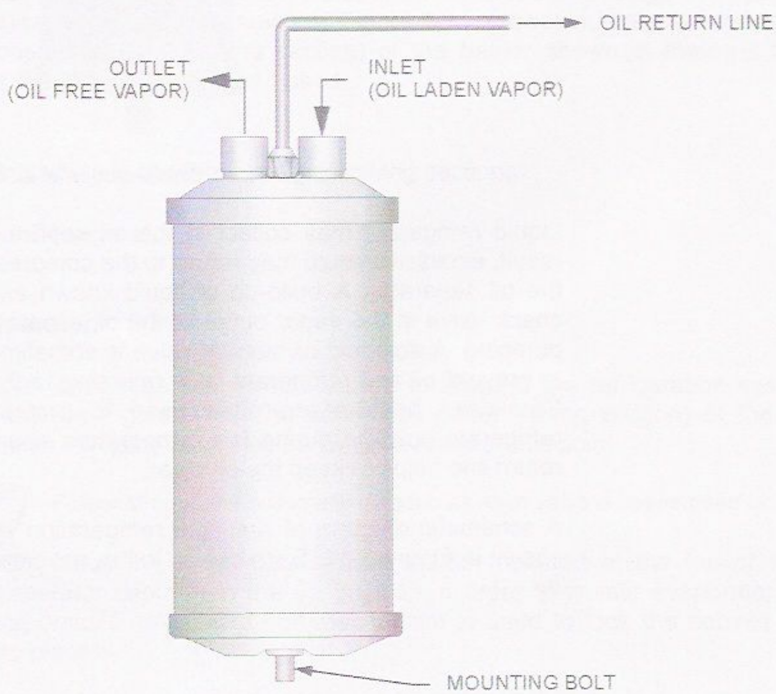


Figure 2-9. Oil separator.

The oil separator removes the oil from the hot compressed vapor as the vapor and oil leaves the compressor. The oil separated from the hot compressed vapor,

falls to the bottom of the separator. The vapor, free from oil, then leaves the oil separator and flows to the condenser. The oil collects in the separator until a certain level is reached. When the oil level is high enough, a float valve arrangement, as shown in Figure 2-10, rises to open a needle valve, to return the oil to the compressor crankcase. The oil returns quickly to the compressor crankcase, since the pressure in the separator is considerably higher than the pressure in the crankcase.

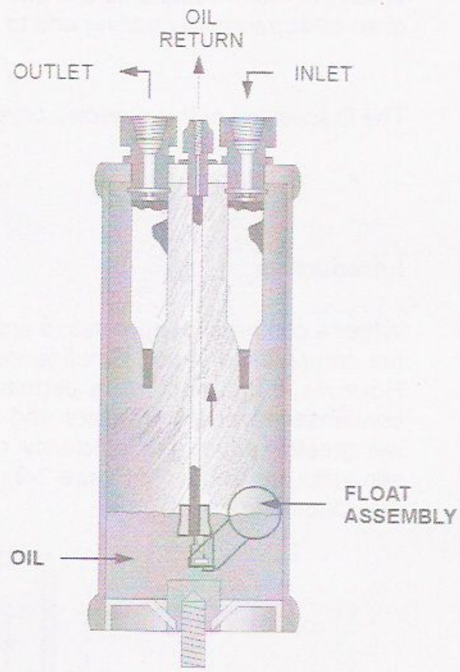


Figure 2-10. Cross-section of an oil separator.

Liquid refrigerant may collect in the oil separator during long off-cycles. As a result, excessive liquid may return to the compressor through the oil return line of the oil separator. A build-up of liquid known as oil pumping or oil slugging. A check valve in the vapor outlet of the oil separator will reduce the chance of oil pumping. A solenoid or manual valve is sometimes installed in the oil return line to prevent oil and refrigerant from returning to the compressor during off-cycles. Crankcase heaters are often used to protect the compressor from liquid refrigerant build-up during low temperature operating periods. A filter in the oil return line helps to keep the oil clean.

A schematic diagram of a simple refrigeration system using an oil separator is shown in Figure 2-11. Each device in this schematic is appropriately labeled.

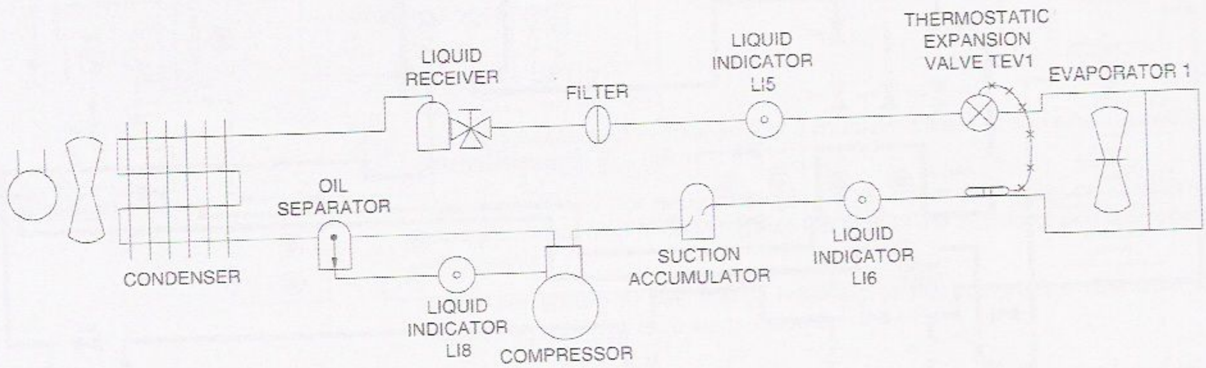


Figure 2-11. Refrigeration system using an oil separator.

Low pressure refrigerant vapor flows from the evaporator to the suction accumulator where liquid refrigerant is separated from the refrigerant vapor. Refrigerant vapor then flows to the compressor where the vapor is heated and discharged at a higher pressure. High pressure refrigerant vapor flows through the oil separator, removing oil from the vapor. Oil free refrigerant vapor then flows to the condenser discharging the heat absorbed from the refrigerated space.

The manual valves which must be opened or closed to arrange this system are not indicated on the schematic of Figure 2-11. However, they are indicated on the schematic panel (tubing section) of the trainer shown in Figure 2-12. The valves that are darkened are closed.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Oil separator

PROCEDURE

Oil separator

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 2-11. The schematic panel (tubing section) of the trainer shown in Figure 2-12 may be used to assist at this point.

   Follow through the schematic diagram as each valve is opened and closed.

   Also, place the evaporator cabinet divider (located at the top of the two evaporator cabinet) in the up position in order to isolate evaporator 1 from evaporator 2. (A sliding bolt mechanism is used to lock the cabinet divider into place).

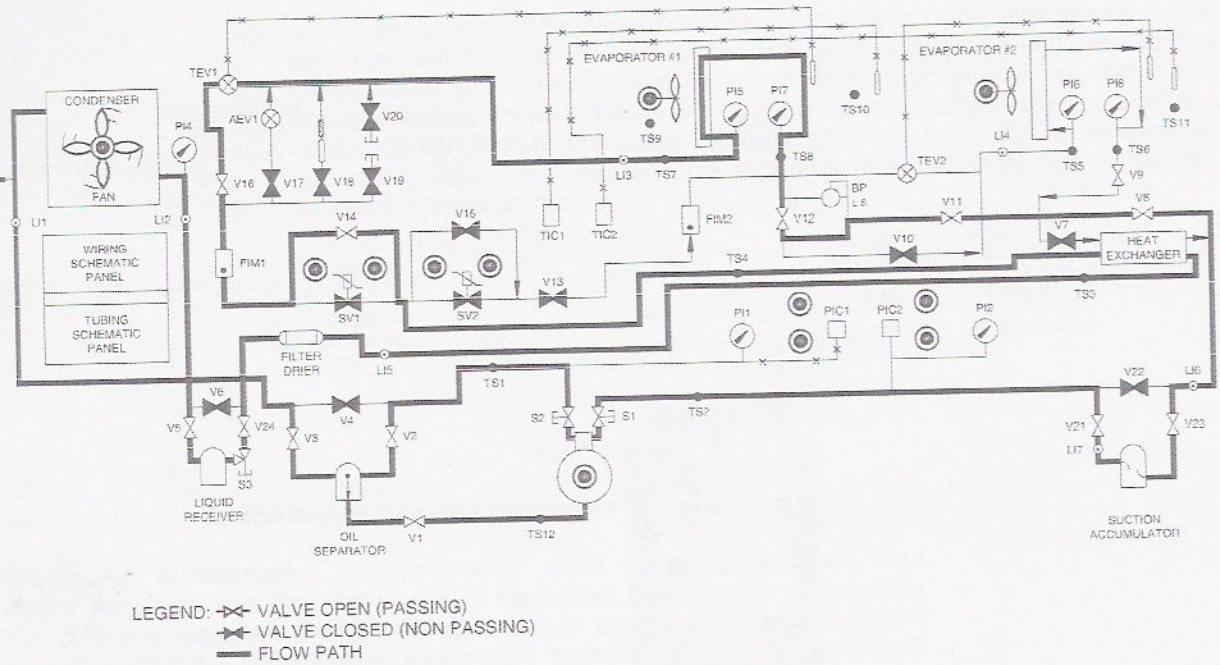


Figure 2-12. Valve configuration.

2. Record which valves are opened and closed.

OPEN VALVES			CLOSED VALVES		
V1	V14		V4	V19	
V2	V16		V6	V20	
V3	V21		V7	V22	
V5	V23		V10	V9	
V8	V24		V13		
~~V10~~			V15		
V11			V17		
V12			V18		

3. Have valves checked by the instructor.

4. Turn on the main input breaker.

5. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to maximum.

6. Turn on the compressor breaker switch to start up the system.

7. Slowly close valve V1 and allow oil to collect in the oil separator while observing the sight glass LI8 and the sight glass on the compressor.

8. Very slowly open V1 while observing sight glass LI8. You should observe that, when V1 is opened, oil returns to the compressor very quickly. Is this what you observed?

   ☒ Yes ☐ No

   The oil is translucent in color so that it could be difficult to see when mixed with liquid refrigerant.

   Moreover, oil will not return through the oil return line if the oil level in the separator is not high enough to raise the float of the separator and open the oil return valve.

   If you are unable to see the oil returning to the compressor (because this occurs very quickly), redo steps 7 and 8.

   Following long off-cycles refrigerant may return through the oil return line. In this event close valve V1 immediately, since excessive amounts of refrigerant entering the crankcase will cause oil pumping or slugging. This condition will be indicated by foaming within the oil level sight glass on the compressor.

9. Turn off the condenser and evaporator fans.

10. Turn off the compressor and mains breaker switch.

CONCLUSION

Oil separators remove oil from the refrigerant vapor that is discharged from the compressor. The oil accumulates in the oil separator and is returned to the compressor through an oil return line. A float and valve assembly returns the oil to the compressor when the oil level in the separator is too high. Oil pumping may occur following long off-cycles. A check valve is therefore placed in the discharge line to the condenser to prevent refrigerant from collecting in the separator.

REVIEW QUESTIONS

1. What is an oil separator and where in a refrigeration system is an oil separator usually found?

   Oil seperator is found between compressor and condencor and prevents oil from going to condensor, filters, expansion valves and evaforator.

2. Why is it important to have an oil separator in some refrigeration systems?

   If oil goes to the evaporator, expansion valves, filters, or condensor it can cause damage.

3. Explain the operation of an oil separator.

Oil – vapor mixture enters the inlet of the oil seperator, the liquid oil drops to the receiver and the vapor refrigerant exits through oil seperator outlet.

4. How does oil get into the refrigerant system?

Oil gets into the system through the oil return line where it's sent to the compressor crankcase.

5. What is oil pumping and how can it be prevented?

Oil pumping is when excess liquid refrigerant/oil is returned to the compressor. It can be prevented by adding a Check valve in the oil sepeletor outlet as well as installing a solenoid valve in the oil return line

Unit Test

1. A liquid receiver is used in a refrigeration system to collect

   a. oil pumped from the compressor.
   b. liquid refrigerant before it enters the compressor.
   c. liquid refrigerant from the condenser.
   d. refrigerant vapor from the evaporator.

2. An oil separator is used in a refrigeration system to collect

   a. oil pumped from the compressor.
   b. liquid refrigerant before it enters the compressor.
   c. liquid refrigerant from the condenser.
   d. refrigerant vapor from the evaporator.

3. Suction accumulators

   a. provide a constant supply of liquid refrigerant to the expansion device.
   b. prevent oil from entering the system.
   c. eliminate the need for a precise refrigerant charge on the system.
   d. prevent liquid refrigerant from entering the compressor.

4. Oil separators are installed in a refrigeration system between the

   a. compressor and the condenser.
   b. evaporator and the compressor.
   c. condenser and the expansion device.
   d. compressor and the liquid receiver.

5. The device which collects liquid refrigerant before it enters the compressor is called

   a. liquid receiver.
   b. oil separator.
   c. liquid collector.
   d. suction accumulator.

6. The expansion device most commonly used in a system with a liquid receiver is a

   a. capillary tube.
   b. thermostatic expansion valve.
   c. automatic expansion valve.
   d. All the above are correct.

7. In a heat pump system, a suction accumulator must be installed between the

   a. condenser and the expansion device.
   b. compressor and condenser.
   c. compressor and reversing valve.
   d. condenser and evaporator.

8. The size of a suction accumulator should not be less than ______ of the total system capacity.

   a. 25%
   b. 50%
   c. 75%
   d. 100%

9. Liquid receivers are installed in a system between the

   a. condenser and expansion device.
   b. evaporator and compressor.
   c. expansion device and evaporator.
   d. compressor and condenser.

10. A device affected by oil in a system is the

    a. condenser.
    b. filter.
    c. expansion device.
    d. All the above are correct.

The Compressor

Unit Objective

Upon completion of this unit, you will be able to describe the operation of, and use for, three types of compressor units.

Discussion Outline

The Discussion of Fundamentals covers the following points:

- New terms and words
- Equipment required

Discussion of Fundamentals

The **compressor** is the heart of a refrigeration system. The refrigeration compressor is a motor driven device that moves hot vapor from the evaporator, compresses it, raising the temperature and transfers it to the condenser. The amount of heat energy given off at the condenser is equal to the **latent heat** energy absorbed in the evaporator plus mechanical heat produced by the compressor. The pressure **differential**, created by the operation of the compressor, is responsible for refrigerant flow within the system.

Several types of compressors used in refrigeration systems are: rotary compressors, consisting of two or more blades rotating on an eccentric shaft to trap vapor and compress it; screw type compressors, consisting of a pair of spiral screws which trap and compress refrigerant vapor as they revolve inside a machined compressor cylinder; centrifugal compressors which rapidly move refrigerant vapor in a circular path such that the **centrifugal force** increases the velocity of the vapor and creates a pressure difference; and **reciprocating** compressors which are the most common type of refrigeration compressor.

The reciprocating compressor operates in a manner similar to the internal combustion engine found in automobiles. This compressor receives its name from the back and forth motion of the piston, which causes the rotary motion of the crankshaft. Reciprocating compressors have the advantage of greater flexibility of design, as well as being easily maintained or repaired.

Three common types of reciprocating compressors are: the hermetic, used mainly in domestic refrigeration units; the **semi-hermetic**, used in larger refrigeration units such as walk-in coolers, and; the open type or the **external drive**, used in larger refrigeration units where the compressor is required to operate at a slower speed than the motor.

Compressors are used for applications such as beverage coolers, walk-in coolers, and air conditioning systems, in automobiles, in restaurants and grocery store coolers, and in other places where refrigeration is used.

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New terms and words

Centrifugal force – a force which tends to pull an object outward when it is rotating rapidly around a center point.

Compressor – the pump in a refrigeration system which draws in low pressure vapor on the cooling side of a refrigeration system and compresses the vapor to a higher pressure on the condensing side of the system.

Crankcase – the part of a compressor which contains the gears, crankshaft, and motor oil.

Differential – the temperature or pressure difference between the high and low sides of a restriction; also the difference of temperature or pressure between the on and off operation of a controller.

External drive – a compressor which uses a drive motor located outside of the compressor housing.

Latent heat – the heat energy which causes a change of state of a substance without a change of temperature.

Reciprocating – back and forth motion in a straight line.

Semi-hermetic – describes the type of compressor which has the drive motor inside the compressor housing and the housing bolted together instead of permanently sealed.

Stator – the position of an electric motor that includes the stationary parts of the magnetic circuit and associated winding and leads.

Equipment required

- Refrigeration System Trainer, Model 3401

Types of Compressors

Exercise Objective

When you have completed this exercise, you will be able to identify three types of compressors.

Discussion Outline

The Discussion of this exercise covers the following points:

- Introduction
- Hermetic Reciprocating Compressors
- Semi-Hermetic Compressor
- Open Type Compressor

Discussion

Introduction

There are several types of reciprocating compressors used for different applications. Factors which determine the type of compressor used are the type of refrigerant, the size of the refrigeration system, and the pressure drop required across the system. The types of compressors discussed in this exercise are:

- Hermetic
- Semi-hermetic
- Open or external type

These three types of compressors are all classified as reciprocating compressors. The classification of compressors is determined by the action of the mechanical operation of the compressor. A reciprocating compressor contains a piston moving back and forth (reciprocating) in a cylinder.

Hermetic Reciprocating Compressors

Hermetic compressors, as shown in Figure 3-1, are totally encased in a sealed housing. The sealed housing contains both the electric motor and the compressor.

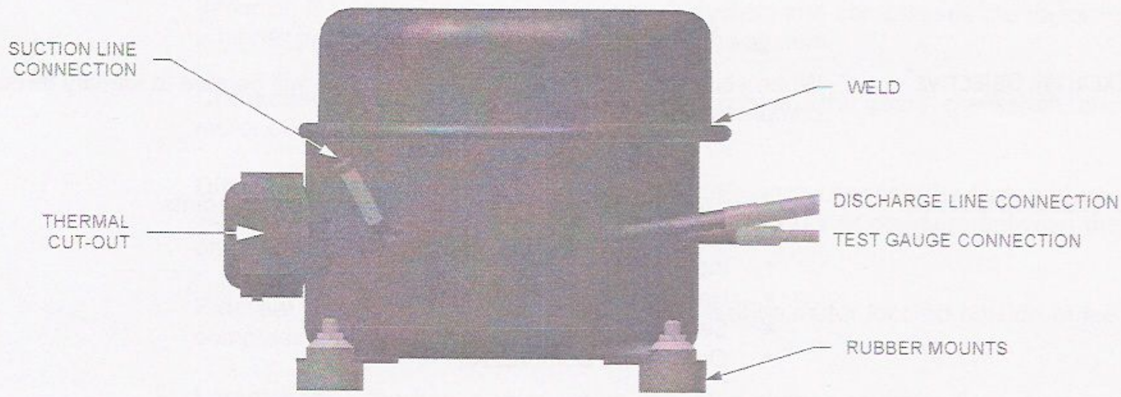


Figure 3-1. Hermetic compressor.

With this type of design, the compressor operates at the speed of the motor, which is driven directly by the motor, and requires no shaft seal. The motor may be mounted either on top of or the bottom of the compressor. The motor is cooled by the transfer of heat from the **stator** to the case and by passing the returning gas around the motor windings before the gas is compressed. This method, however, reduces the efficiency of the compressor since the returning gas is warmed. Hermetic compressors are extremely difficult to repair since the compressor casing is welded closed.

Figure 3-2 illustrates the cross-sectional view of a hermetic compressor with the motor at the bottom and the compressor at the top. Note that the compressor has only one piston and the motor is connected directly to the crankshaft. The rotation of the motor and the crankshaft, provides the action for the piston to travel back and forth within the cylinder. The unit is usually spring mounted inside the hermetic dome in order to prevent compressor vibration from being transferred outside the dome. The exhaust and suction lines inside the dome are flexible to prevent damage to the lines from the continuous vibration of the motor and compressor. The electrical connections to the motor pass through the dome by means of an insulated leak proof seal.

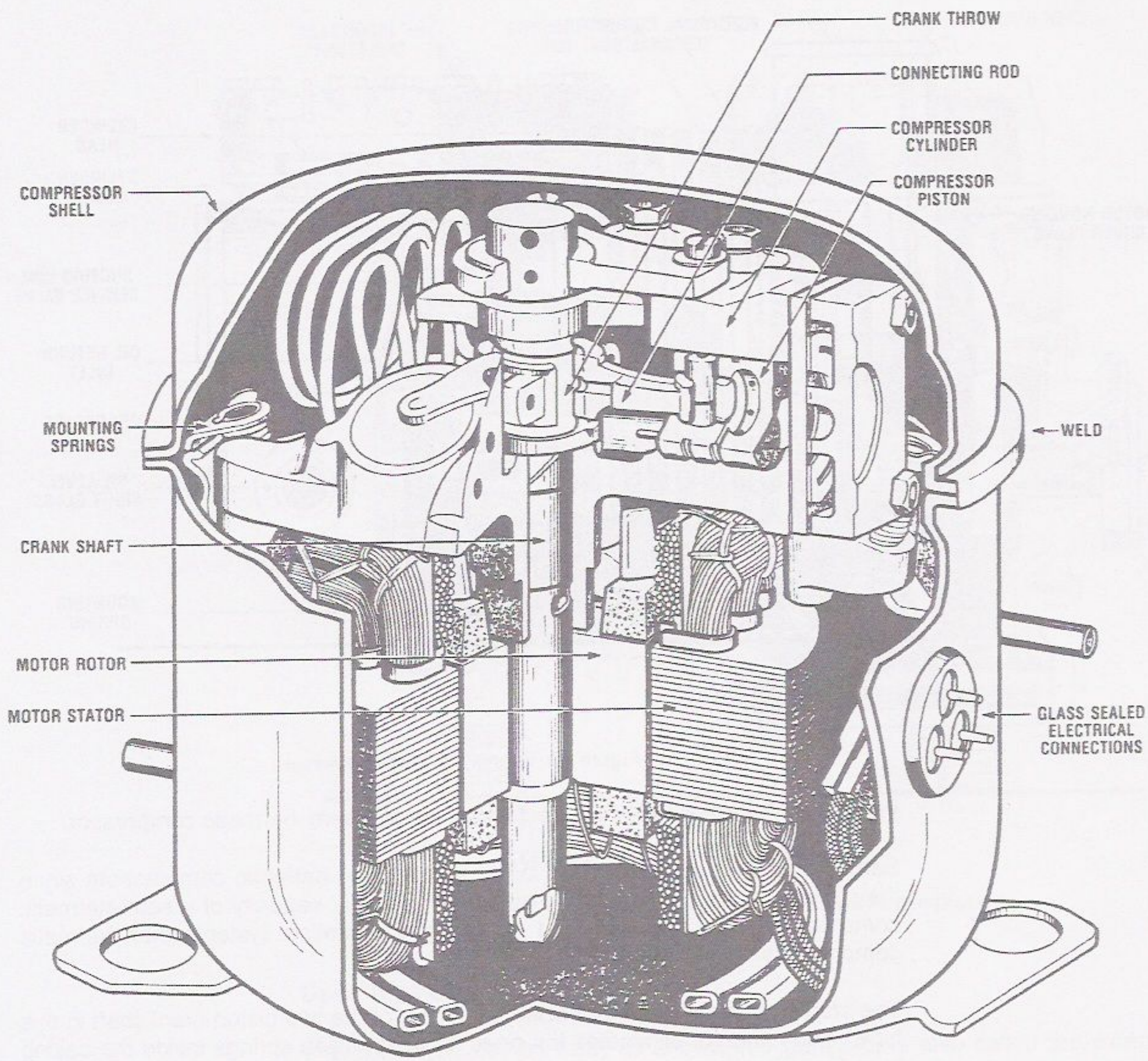


Figure 3-2. Cross-sectional view of a hermetic compressor.

Semi-Hermetic Compressor

The semi-hermetic compressor, as shown in Figure 3-3, is also called a serviceable hermetic compressor. This compressor also contains both electric motor and compressor in one unit. This type of unit is bolted rather than sealed, and may be taken apart and reassembled.

The compressor operates at motor speed, since it is driven directly by the motor and requires no shaft seal.

The motor is cooled by the transfer of heat from the stator to the casing and by passing the returning gas around the motor windings before the gas is compressed. This reduces the compressor efficiency since it warms the returning gas.

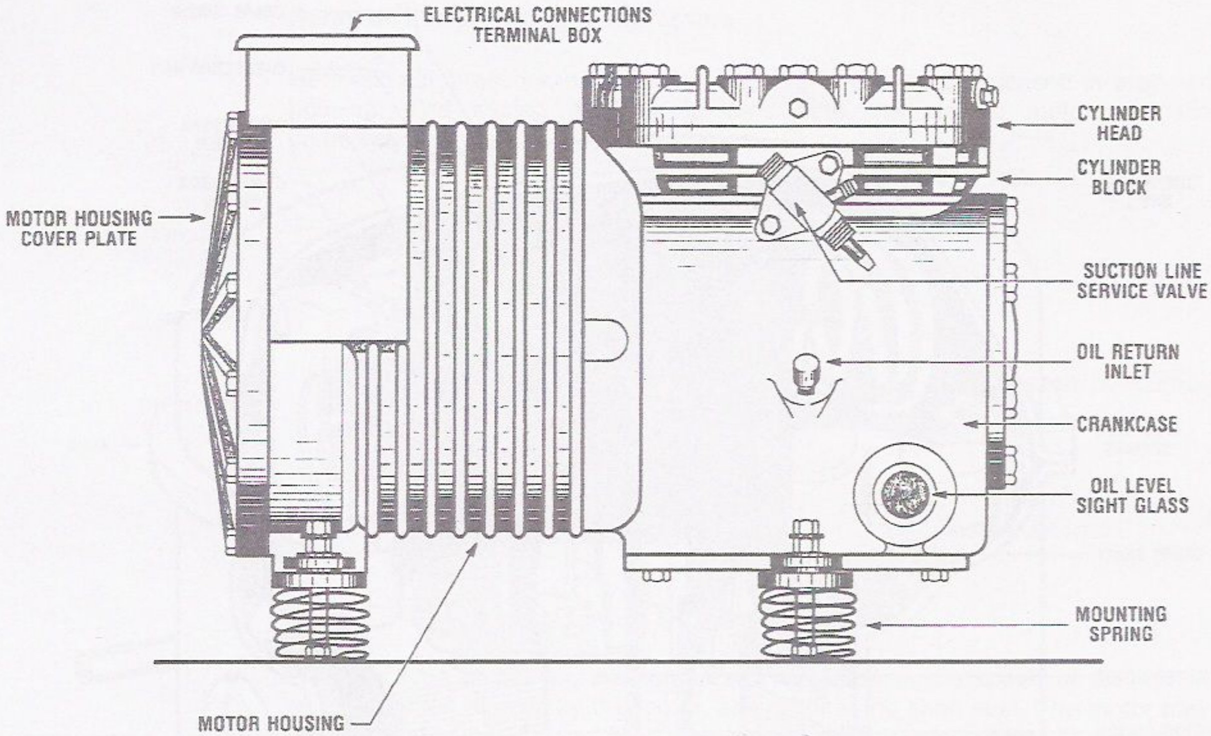


Figure 3-3. Semi-hermetic compressor.

Figure 3-4 illustrates the cross-sectional view of a semi-hermetic compressor.

Semi-hermetic compressors are larger in size than hermetic compressors since they usually contain two or more pistons. The larger capacity of a semi-hermetic compressor allows it to be used on larger refrigeration systems than hermetic compressors.

The sturdy construction and precise balancing of the two piston crankshaft in this type of compressor eliminates the need for suspension springs inside the casing to reduce vibrations.

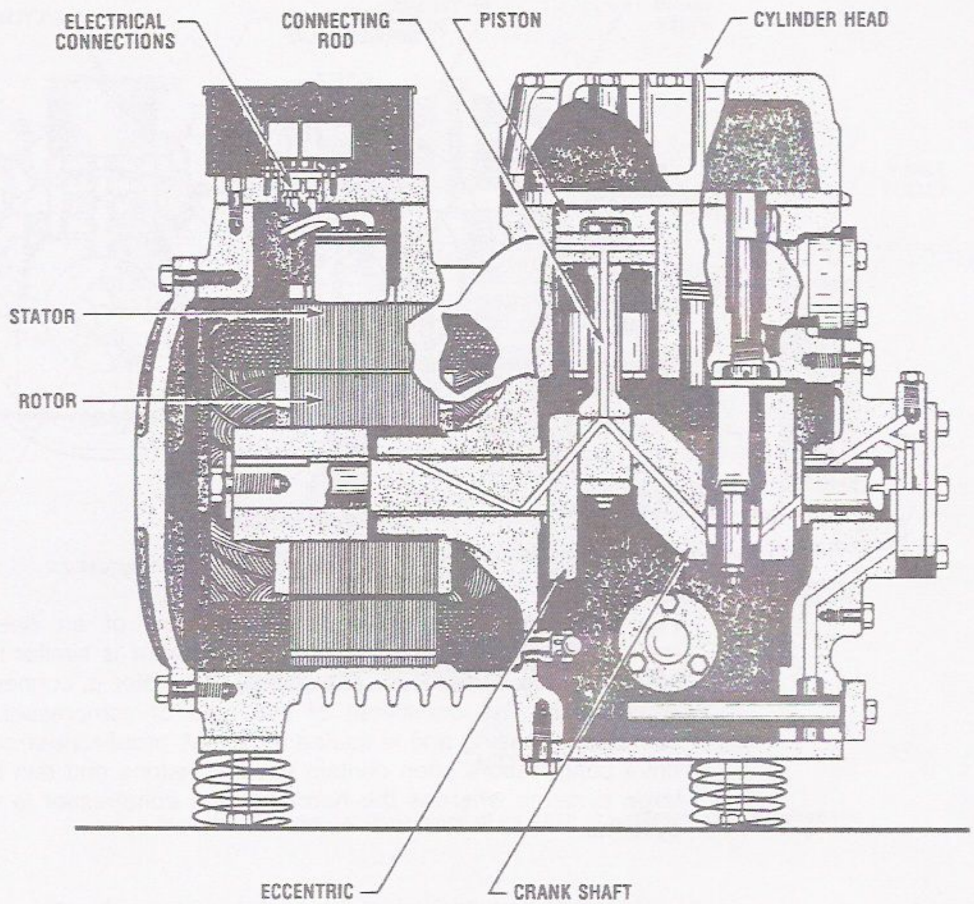


Figure 3-4. Cross-sectional view of a hermetic compressor.

Open Type Compressor

The open type compressor, as shown in Figure 3-5, is also called the external drive compressor. The drive motor and compressor on this unit are separate. The crankshaft of the compressor extends through the **crankcase** and is driven by a pulley and belt, or can be driven directly by an electric motor. A crankshaft seal is required where the crankshaft comes through the crankcase.

The external drive compressor is usually driven at less than the motor speed. This requires that the motor belt pulley be smaller than the compressor pulley. The size of the drive pulley on the motor and the pulley on the compressor govern the speed of the compressor.

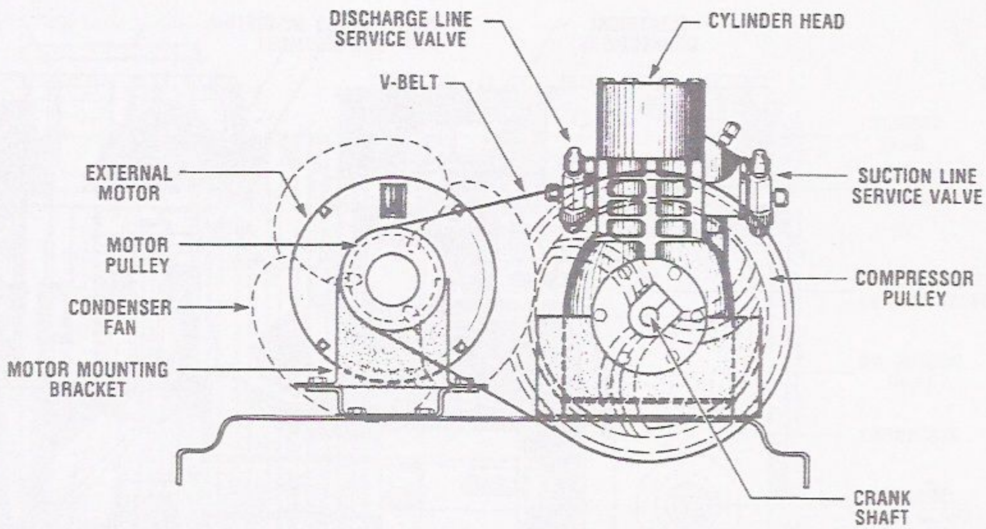


Figure 3-5. Open type compressor.

Figure 3-6 illustrates a cross-sectional view of an open or external drive compressor. Note that this type of compressor is similar in construction to the semi-hermetic compressor except that the motor is connected externally to the compressor. The crankshaft of this type of compressor extends out of the compressor casing and is sealed by a leak proof rubber seal. Open or external drive compressors often contain several pistons and can be used on relatively large systems whereas the hermetic type compressor is used mainly in small systems.

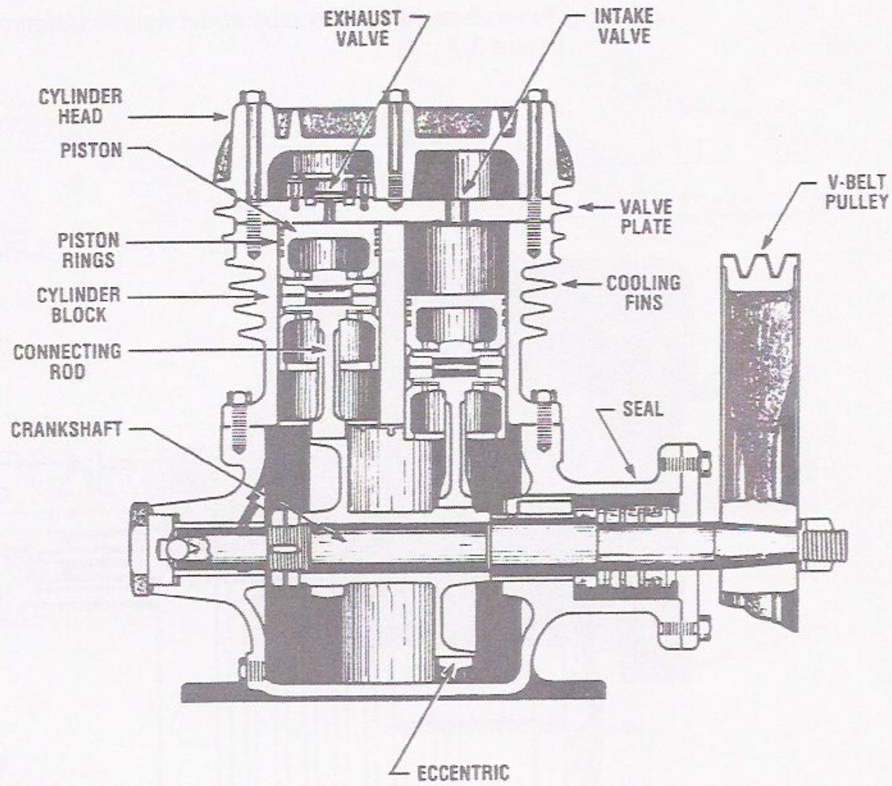


Figure 3-6. Cross-sectional view of an open or external type compressor.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Types of compressor

PROCEDURE

Types of compressor

1. Examine the compressor of the Refrigeration System Trainer.

2. Describe the type of compressor used on the trainer.

____

____

____

3. Observe and list each part of the semi-hermetic compressor as indicated in Figure 3-7.

a. motor housing
b. terminal box
c. cylinder head
d. cylinder block
e. service valve
f. oil return inlet
g. crank-case
h. sight glass
i. mounting spring
j. motor housing

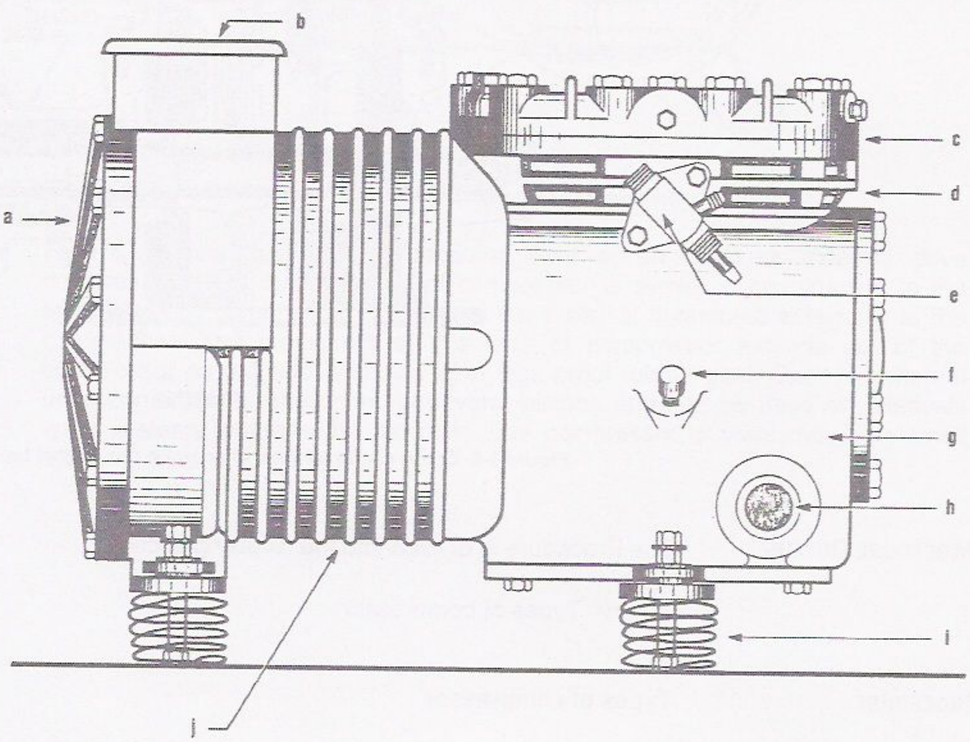


Figure 3-7. Parts of a semi-hermetic compressor.

4. Briefly describe the function of each device on the semi-hermetic compressor.

A – contains the motor inside
B – houses the electrical connections
C – top of the cylinder, ~~hous~~ inlet at outlet ports
D – contains the cylinders and pistons that compress
E – used to add / remove refrigerant
F – allows oil to return from oil seperator
G – contains gears, crankshaft and motor oil
H – indicates moisture/oil in system
I – prevents external vibration from compressor.
J – contains the motor.

5. List each part on the hermetic compressor in Figure 3-8.

a. suction line	d. testing port
b. weld	e. rubber mounts
c. discharge line	f. thermal cut-out

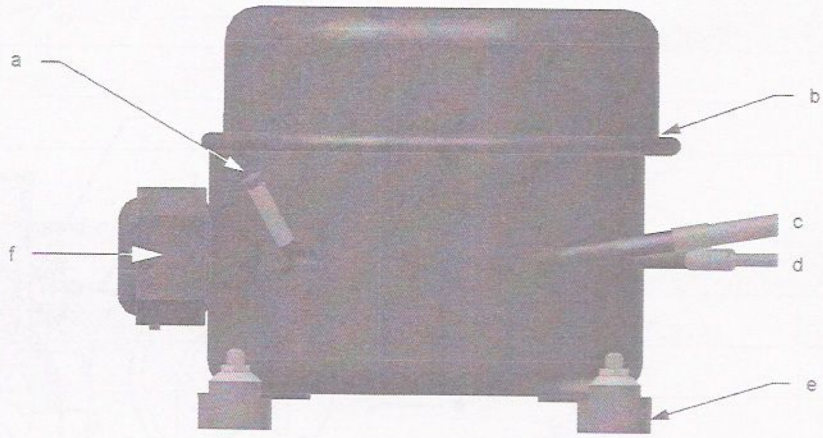


Figure 3-8. Parts of hermetic compressor.

6. List each device on the external drive compressor in Figure 3-9.

a.	mounting bracket	f.	discharge service valve
b.	condensor fan	g.	cylinder head
c.	motor pulley	h.	suction service valve
d.	motor	i.	compressor pulley
e.	V belt	j.	crank shaft

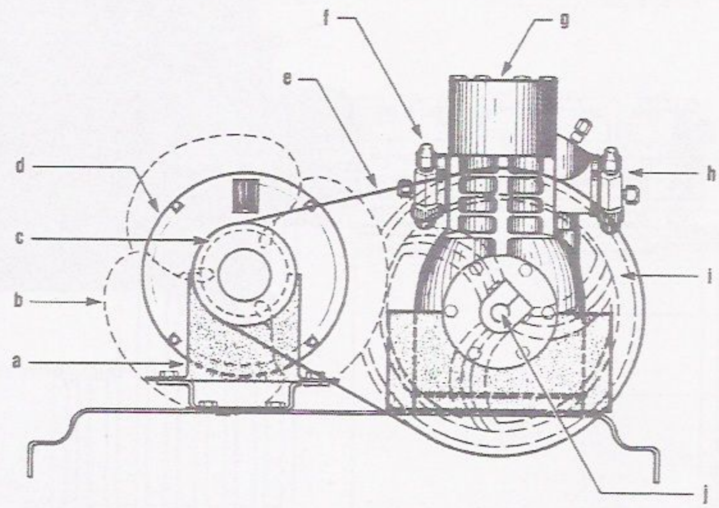


Figure 3-9. Parts of an external drive compressor.

7. Return the trainer.

Conclusion

Three types of reciprocating compressors are the hermetic, the semi-hermetic, and the open type. These compressors require a piston to move back and forth in a cylinder to operate. The method used to cool the motor on the hermetic compressors is by bypassing returning gas around the motor windings.

On the open or external drive compressor unit, the motor and compressor are separate. The compressor is driven by the motor using a belt and pulley. The alignment of the drive pulley must be correct in order to avoid excessive belt wear and damage to the pulley bearings.

Review Questions

1. What factors affect the type of compressor for use in any application?

The system type, its size, type of refrigerant as well as the pressure drop.

2. What classification of compressor are hermetic, semi-hermetic or open compressors?

   They are all reciprocating compressors

3. Where is the electric motor located on a hermetic compressor?

   It can be located at the top or bottom

4. What is meant by the term semi-hermetic?

   It means it's bolted, rather than sealed, and can be opened up.

5. Describe the drive connection between the motor and compressor of an external drive compressor.

   The motor will run at a higher speed than the compressor on an external-drive compressor. The pulley size of both the motor and compressor determine the speed (smaller motor pulley = less compressor speed)

Operation of the Compressor

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to explain the operation and test the efficiency of a reciprocating compressor.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Compressor efficiency (volumetric efficiency)
- Compression ratio

DISCUSSION

Compressors produce a pressure differential between the high and low sides of the refrigeration system. This is achieved by the pumping of low pressure refrigerant vapor from the suction (evaporator) side, through the compressor, to the high pressure (condenser) side of the system. The compression of the vapor causes the transfer of heat energy from the low side to the high side of the system.

There are four main groups of compressors: 1) reciprocating 2) rotary 3) centrifugal and 4) screw compressors. All four groups of compressors perform the same function, but their internal methods of compressing refrigerant vapor are different. The most common compressor is the reciprocating compressor and is used on the Refrigeration System Trainer. The operation of the reciprocating compressor will be investigated in this exercise.

Reciprocating compressors are a piston-cylinder type of pump. The main parts include a cylinder, piston, connecting rod, crankshaft, cylinder head and valves. The operating cycle of a reciprocating compressor is shown in Figure 3-10.

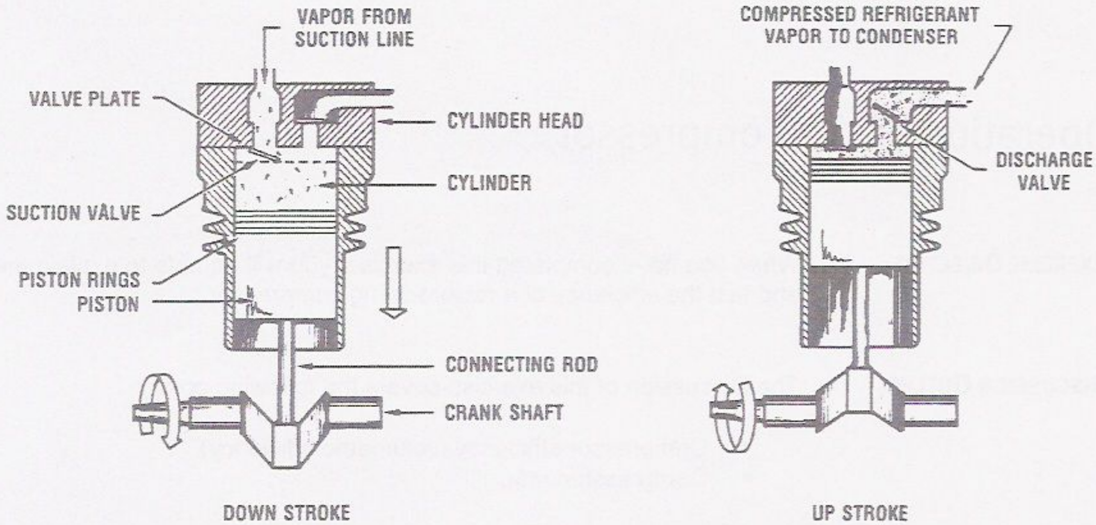


Figure 3-10. Operation cycle of a reciprocating compressor.

The compressor is operated by means of an electric motor which turns the compressor crankshaft. On the down stroke of the piston, a low pressure area is created between the top of the piston, the cylinder head and the suction line of the evaporator. Cold refrigerant vapor rushes through the suction valve inlet and into the low pressure area. On the up stroke, the suction valve closes and the exhaust (discharge) valve is forced open with the increasing pressure. The vapor is compressed and forced into the discharge (high) side of the refrigeration system. When the piston reaches the top of the cylinder, the discharge valve closes, and the suction valve opens as the piston again draws in cold refrigerant vapor to complete the cycle.

Note that the connecting rod attached between the crankshaft and piston serves to change rotary motion into reciprocating (back and forth) motion. The piston rings prevent the vapor from escaping between the piston and cylinder walls and improves the operating efficiency. The compressor housing or crankcase contains the bearing surfaces for the crankshaft and stores the oil that lubricates the compressor parts.

Compressor efficiency (volumetric efficiency)

The efficiency of a compressor may be measured by the amount of energy used relative to the energy wasted during a desired function. This measure of efficiency may be indirectly specified using volumetric efficiency. Volumetric efficiency is the ratio between the volume of refrigerant actually pumped per revolution of the compressor, divided by the volume calculated from the bore and stroke of the piston. For small compressors used in domestic refrigeration systems, the volumetric efficiency varies between 40 and 75 percent, with 60 percent being an average value. The larger commercial compressors have volumetric efficiencies between 50 and 80 percent, with 70 percent being an average value.

The physical condition of the compressor directly affects the volumetric efficiency of the unit. A bad suction valve, which does not close tightly on the compression stroke, will allow some of the hot pressurized refrigerant vapor to be forced out

the suction valve and into the suction line, only to be pulled back into the cylinder on the next suction stroke. This reduces the efficiency of the compressor. In a similar manner, if the discharge valve does not close tightly on the suction stroke, it is possible that some of the previously discharged vapor will be pulled back into the cylinder. This will decrease the amount of suction vapor that is able to enter the cylinder and again reduce the volumetric efficiency. The efficiency will be decreased by worn or broken piston rings since there will not be a tight seal between the piston and the cylinder wall. This will allow refrigerant vapor to leak into the crankcase and lower the discharge pressure obtainable by the compressor.

There are several tests that may be performed on the compressor to determine its general condition. The suction line may be closed off as near to the compressor as possible and allow the compressor to pump a vacuum. It is difficult for even a good compressor to achieve a vacuum lower than −68 kPa (20 inHg), therefore if the compressor pumps a lower vacuum it can be assumed that the piston and rings are in good condition, as well as the cylinder head valves. Once a vacuum has been achieved, the compressor may be turned off and the suction pressure observed. If the vacuum pressure increases rapidly, the compressor may need to be examined more closely. The same type of test can be performed on the discharge side of the compressor by pumping a positive pressure of approximately 1380 kPa (200 psi).

Efficiency of the compressor is also dependent on operation in the proper pressure ranges. The suction pressure must not be maintained at too low a level and the discharge pressure must not be maintained at too high a level. Excessive strain may be placed on the compressor drive motor when the pressure differential is too great between the high and low sides of the system.

Compression ratio

The compression ratio of a compressor is a means of determining the efficiency of a compressor when using a particular refrigerant. This ratio is the relationship between the absolute pressure on the suction side to the absolute pressure on the discharge side of the compressor.

Table 3-1 lists the recommended compression ratios for different refrigerants under normal conditions of 30°C (86°F) condensing temperature and −15°C (5°F) evaporating temperature.

Table 3-1. Compression ratio for typical refrigerants under normal conditions of 30°C (86°F) condensing temperature and −15°C (5°F) evaporating temperature.

Refrigerant	Compression ratio
R–22	4.06
R–717	4.94
R–718	6.95
R–744	3.10
R–764	5.61

For the R-134a refrigerant, the recommended compression ratio is **4.7** under normal conditions of 54.4°C (130°F) condensing temperature and 1.7°C (35°F) evaporating temperature.

Compression ratio is of prime importance when it approaches its upper limit. A high compression ratio denotes either a high head pressure and/or a low suction pressure. This results in loss of efficiency since the discharge vapor will become excessively superheated and the exhaust valve of the compressor will overheat. This will ultimately cause damage to the compressor. To achieve compression ratios higher than the recommended value, multiple stage compressors must be used.

A schematic diagram of a typical refrigeration system is shown in Figure 3-11. This system will be used to test the efficiency of the compressor.

The manual valves which must be opened or closed to arrange this system are not indicated on this schematic. However, a pictorial diagram of the system panel as shown in Figure 3-12 indicates the open and closed manual valves.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Test for holding of suction pressure
- Determining the compression ratio

PROCEDURE

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 3-11. The schematic panel (tubing section) of the trainer shown in Figure 3-12 may be used to assist you at this point.

   Follow through the schematic diagram as you open and close each valve.

   Also, place the evaporator cabinet divider (located at the top of the two evaporator cabinet) in the up position in order to isolate evaporator 1 from evaporator 2. (A sliding bolt mechanism is used to lock the cabinet divider into place).

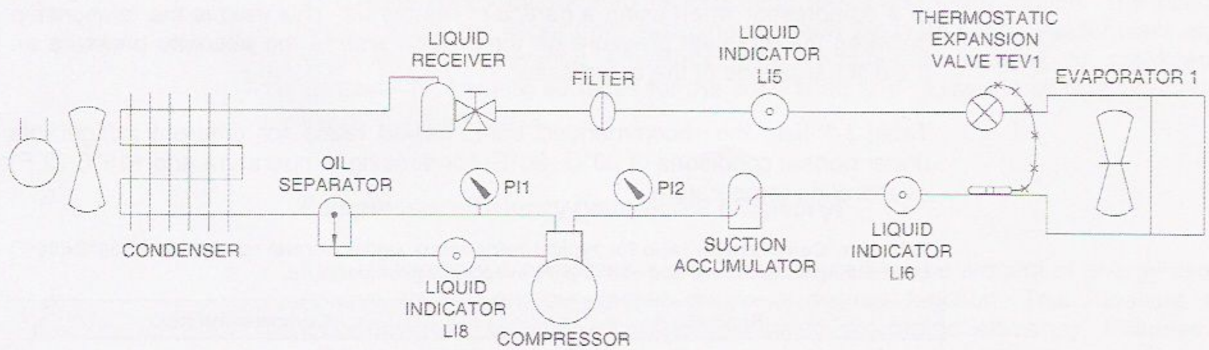
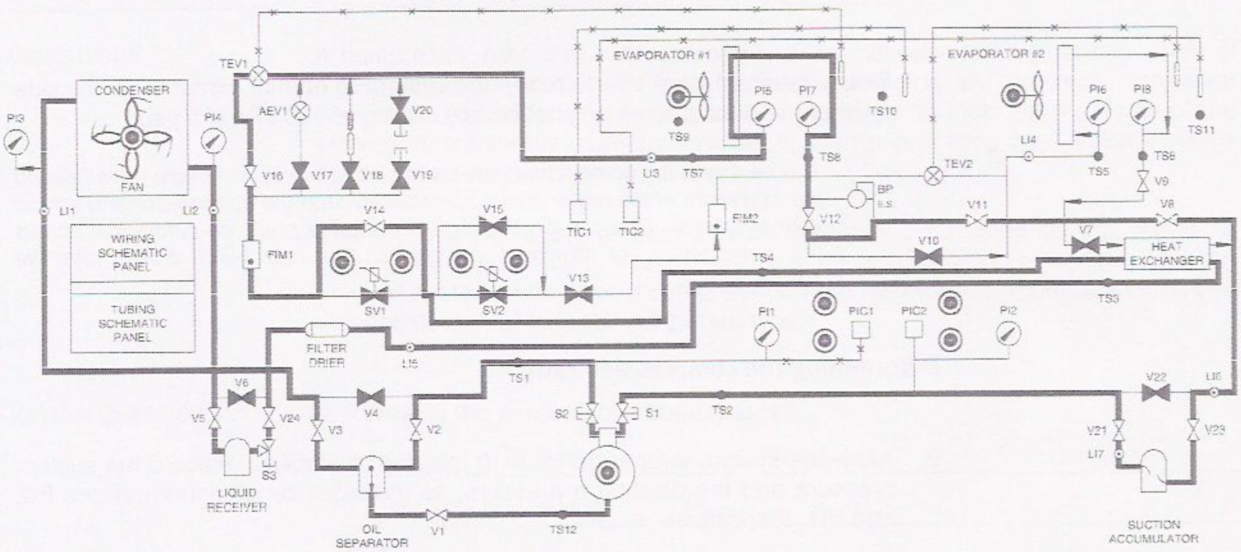


Figure 3-11. Typical refrigeration system.

2. Record which valves are opened and closed.

OPEN VALVES			CLOSED VALVES		
V16	V12		V17	V7	
V5	V11		V18	V9	
V24	V8		V15		
V14	V1		V6		
V3			V4		
V2			V13		
V21			V10		
V23			V22		

3. Have valves checked by the instructor.



LEGEND: VALVE OPEN (PASSING)
VALVE CLOSED (NON PASSING)
FLOW PATH

Figure 3-12. Valve configuration.

4. Turn on the mains input breaker.

5. Set the evaporator-1 fan speed and condenser fan speed to maximum.

Test for holding of suction pressure

6. Adjust the low pressure controller to its highest vacuum setting to prevent it from shutting down the system. Then close valve V23 to cut off the suction line from the rest of the system.

7. Allow the compressor to operate until the suction pressure falls to approximately −51 kPa (15 inHg), **then turn it off**. While the compressor is running, note and record the suction line pressure reached **after two minutes**.

   __Do not allow__ the compressor to operate for more than three minutes at high vacuum pressure. Damage may result.

   Vacuum pressure after two minutes = ______ kPa or ______ inHg

   After the compressor is turned off, describe the pressure variation (i.e. slow, medium or fast decrease in vacuum pressure). What does this indicate about the condition of the compressor?

   ____

   ____

   ____

8. Slowly re-open valve V23 to return the system to normal. Return the low side pressure controller to its original factory setting of 103 kPa (15 psi).

   The next time the compressor is restarted, if the ammeter needle goes beyond the maximum of the meter scale, immediately stop the compressor and advise your instructor. This can be due to an excessive pressure differential across the compressor, or to liquid refrigerant that has been drawn into the compressor.

Determining the compression ratio

9. Allow the system to operate for 5-10 minutes to stabilize. Record the suction pressure and the discharge pressure, as indicated by pressure gauges PI2 and PI1, respectively.

   Suction pressure (PI2): ______ kPa or 22 psi

   Discharge pressure (PI1): ______ kPa or 124 psi

10. Calculate the compression ratio:

$$\text{Compression ratio} = \frac{\text{Absolute discharge pressure}_{(\text{kPa abs./psia})}}{\text{Absolute section pressure}_{(\text{kPa abs./psia})}}$$

   To convert a gauge pressure reading into absolute pressure, add the atmospheric pressure (101.3 kPa abs. or 14.7 psia) to obtain the equivalent absolute pressure.

   ____

Given a theoretical compression ratio of 4.7 for the R-134a refrigerant, under normal conditions of 54.4°C (130°F) condensing temperature and 1.7°C (35°F) evaporating temperature. How does the experimental result recorded above differ from this theoretical figure?

____

____

____

____

11. Turn off the condenser and evaporator fans.

12. Turn off the compressor and mains breaker switch.

CONCLUSION

A compressor produces a pressure differential between the high and low side of a refrigeration system. This is achieved by pumping low pressure refrigerant vapor from the evaporator through the compressor and into the high side of the system. A commonly used compressor is the reciprocating type which involves the back and forth motion of a piston.

The efficiency of a compressor can be determined by using several methods: suction pressure holding, head pressure holding and compression ratio test. An efficient system must have a compression ratio below a maximum recommended value, determined for each refrigerant type.

REVIEW QUESTIONS

1. What is the purpose of a compressor?

To create a pressure differential between the low and high side of the system.

2. Explain the operation of a reciprocating compressor.

It consists of two valves, a piston cylinder, intake and exhaust ports and connecting rod. Vapor is forced into the cylinder on the downstroke and is compressed on the upstroke

3. What are three other types of compressors?

Rotary, centrifugal and screw compressors.

4. How is the efficiency of a compressor tested?

The efficiency is tested by closing off the suction line and pumping a vacuum into the compressor. If the vacuum is low, the compressor is operating properly. If

5. Why is a compression ratio important?

It's important because it shows the compressor is not overheating, which may cause damage. High compression ratios will cause high discharge pressure, which will overheat the discharge valve.

Compressor Test Equipment

Exercise Objective

When you have completed this exercise, you will be able to use various compressor testing devices and techniques commonly used when troubleshooting a refrigeration system.

Discussion Outline

The Discussion of this exercise covers the following points:

- Wattmeter
- Volt-ammeter
- Hermetic compressor analyzer (capacitance tester)
- Compressor test cord

Discussion

The maintenance, troubleshooting, and repair of compressor motors is a major part of maintaining the proper operation of any refrigeration system. Various motor testing devices and techniques are available to assist in the troubleshooting procedure

which may prevent the needless replacement of hermetic compressor units. Using these devices, it can be determined whether internal or external faults are responsible for improper operation of a refrigeration system compressor.

Wattmeter

The condition of a compressor motor can often be determined by observing the wattage consumption of the unit. A wattmeter is used to measure the power consumed (true power in watts) by a compressor motor. This value will change as the system cycles the compressor.

At the instant the compressor motor starts, the wattmeter needle will swing to a high value and then return back to a normal operating value, as shown in Figure 3-13.

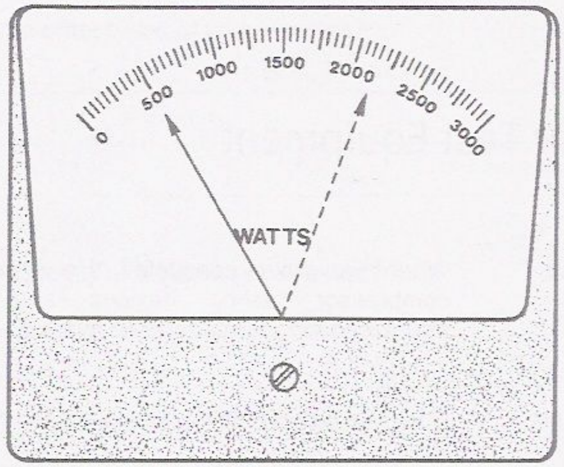


Figure 3-13. Typical wattmeter readings.

For example, if the starting winding circuit is open, the wattmeter needle will swing to the right and settle to the running winding value immediately. The absence of the combined winding reading indicates a bad relay or starting winding. The overload safety cut-out should open the circuit in two or three seconds.

Too high a wattage reading indicates excessive load on the compressor motor, possibly caused by excessive friction in the motor or too high a pressure differential between the suction and discharge sides of the compressor. This may cause the motor to overheat or burn out. Too low a wattage reading indicates too light a load on the motor, which may be caused by a low compression ratio (worn rings or valves) or low refrigerant charge on the system.

Approximate power consumption for small hermetic motors are listed in Table 3-2.

Table 3-2. Power consumption of compressors.

Motor size	Power consumption at 120 V		
	Running		Starting or locked
	At 21°C (70°F)	At 43°C (110°F)	
47 W (0.0625 hp)	66 W	100 W	375 W
93 W (0.125 hp)	108 W	163 W	743 W
187 W (0.25 hp)	235 W	320 W	1250 W
373 W (0.5 hp)	430 W	690 W	2100 W

Volt-ammeter

To help check the electrical circuits in a motor, the manufacturer usually lists the volt-ampere (VA) values for their equipment. This is the apparent power consumed (in volt amperes) by the compressor motor. This value should not change as the load on the compressor varies.

If this value does change, it is usually an indication of faulty internal wiring of the compressor motor windings.

Note that individual voltmeters and ammeters can be used to test the VA of the compressor motor.

Hermetic compressor analyzer (capacitance tester)

When a compressor motor does not operate properly, the trouble could be the motor capacitor. Most motors only have a starting capacitor but others may have a starting capacitor and a running capacitor.

The simplest capacitor test is to substitute a good capacitor for the one in question. The replacement capacitor should be equal to or up to 25 percent over capacity rather than under capacity. However, if the capacitance is not known for the motor capacitor, a hermetic compressor analyzer (capacitance tester) may be used to determine the correct capacitance. This meter has a variable capacitance which increases in micro-farads until sufficient capacitance has been placed in series with the motor to bring it up to the correct voltage. The capacitance registered on the selector indicates the capacitor size that should be placed in the circuit.

Compressor test cord

Test cords can be used to check the compressor operation independent of the rest of the electrical circuitry. The test cord is connected directly to the compressor and allows the testing of the starting capacitor, running capacitor, and motor windings. Figure 3-14 illustrates the use of a test cord to check a capacitor-start, capacitor-run hermetic motor. A capacitor-start, induction-run hermetic motor can be tested by omitting the running capacitor and making a connection directly to the running winding.

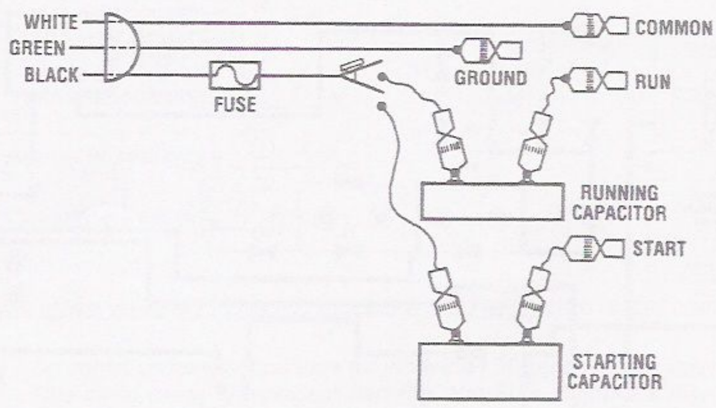


Figure 3-14. Test cord connections for compressor testing.

A schematic diagram of a typical refrigeration system is shown in Figure 3-15. This system will be used to check the power consumption of the compressor motor.

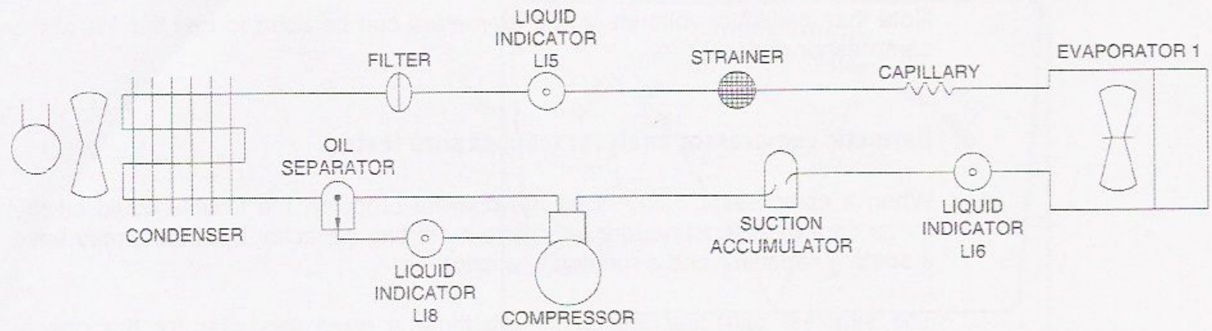


Figure 3-15. Typical refrigeration system.

The manual valves which must be opened or closed to arrange this system are not indicated on this schematic. However, a pictorial diagram of the system panel as shown in Figure 3-16 indicates the open and closed manual valves.

Procedure Outline

The Procedure is divided into the following sections:

- Compressor test equipment

Procedure

Compressor test equipment

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 3-15. The trainer's schematic panel (tubing section) shown in Figure 3-16 may be used to assist at this point.

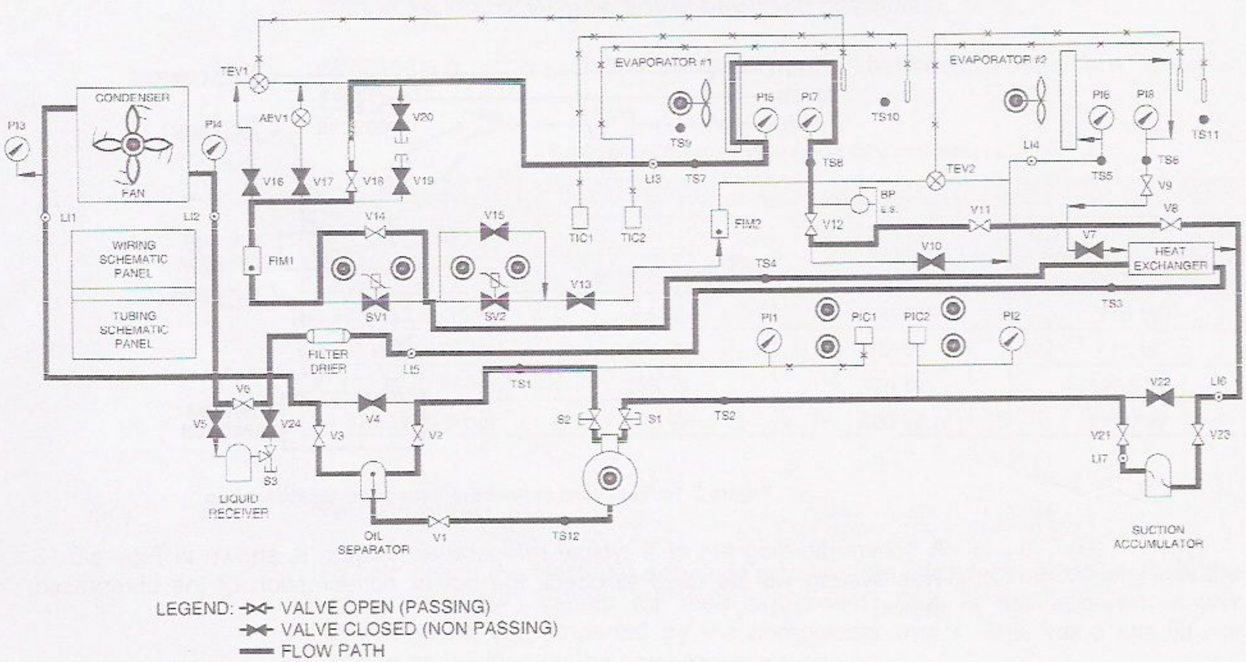


Figure 3-16. Valve configuration.

2. Record which valves are opened and closed.

OPEN VALVES			CLOSED VALVES		
V18	V8		V16	V22	
V14	V1		V17	V10	
V3			V5	V9	
V2			V24	V7	
V21			V6		
V23			V15		
V12			V4		
V11			V13		

3. Have valves checked by the instructor.

4. Turn on the main input breaker. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to medium.

5. Turn on the compressor breaker switch. Allow the system to operate for five minutes to stabilize.

6. Observe and record the wattmeter, voltmeter and ammeter readings.

   Calculate the volt-ampere (VA) reading by multiplying the voltmeter and ammeter readings together and record.

   Wattmeter reading = 500 W

   Voltmeter reading = 107 V

   Ammeter reading = 8.2 A

   Calculated VA = 877.4 A

7. Slowly close valve V2. This will block the discharge side of the compressor.

   Do not let compressor operate for more than 30 seconds with valve V2 closed. This could cause compressor damage. Pressure controllers may have to be adjusted to prevent the system from cycling.

8. Carefully observe and record the wattmeter, voltmeter and ammeter readings. (The variations in meter readings might be quite low). Open valve V2 when readings are recorded.

   Wattmeter reading = 550 W

   Voltmeter reading = 107 V

   Ammeter reading = 8.4 A

   Calculated VA = 898.8 A

   Did the wattage and VA readings change from the readings calculated in procedure step 6? Explain.

   Yes, they jumped a little, because there was a bigger load on compressor

9. Turn off the condenser and evaporator fans.

10. Turn off the compressor and mains breaker switch.

CONCLUSION

Maintenance, troubleshooting and repair of a compressor motor is a major part of a refrigeration technician's job.

Wattmeters are used to measure the power consumed by the compressor motor. This value will vary as the load on the compressor motor varies. A volt meter and ammeter can be used to determine the compressor volt-ampere (VA) consumption. This value should not change as the load on the compressor motor varies.

A hermetic compressor analyzer is used to determine the correct capacitor size for the compressor being used.

A compressor test cord operates the compressor independent of the system's controls.

REVIEW QUESTIONS

1. How is a wattmeter used to test a compressor motor?

   It's used to check if the motor is drawing too much power. Too high a power draw indicates excessive pressure differences, or a problem with the motors or windings.

2. How is excessive load on the compressor indicated on a wattmeter?

   The needle will jump or climb to a high value and stay there.

3. When will a volt-ampere reading on a compressor motor change and why?

   It will change as the load on the compressor varies, this is a sign of bad wiring in the motor windings.

4. What is an easy way to test the capacitor of a compressor motor?

   Replace it with another capacitor of a rating not more than 25% more the capacity of the current one.

5. How do you determine the proper capacitor size for a particular compressor motor?

   Use a hermetic compressor analyzer, it increases its capacitance until there's enough to start the compressor.

Unit Test

1. Compressors that have a piston and crankshaft and operate in a similar manner to an automobile engine are called

   a. centrifugal compressors.
   b. reciprocating compressors.
   c. rotary compressors.
   d. screw compressors.

2. A common type of reciprocating compressor is called

   a. hermetic.
   b. semi-hermetic.
   c. external drive.
   d. All the above are correct.

3. A compressor which is totally encased and bolted together is called

   a. an external drive.
   b. hermetic.
   c. semi-hermetic.
   d. All the above are correct.

4. When the piston moves away from the valve plate in a reciprocating compressor, it is called

   a. reverse stroke.
   b. forward stroke.
   c. up stroke.
   d. down stroke.

5. When the piston moves toward the valve plate in a reciprocating compressor, the suction valve is

   a. open.
   b. partially open.
   c. closed.
   d. partially closed.

6. The compression ratio of a compressor is determined by the

   a. discharge pressure over the suction pressure.
   b. suction pressure over the discharge pressure.
   c. evaporator pressure over the condenser pressure.
   d. condenser pressure over the evaporator pressure.

7. A wattmeter measures

   a. apparent power in VA.
   b. true power in watts.
   c. reactive power in VAR.
   d. None of the above is correct.

8. A hermetic compressor analyzer is used to test the

   a. compressor motor windings.
   b. power consumption of the compressor motor.
   c. required operating capacitance for a compressor motor.
   d. efficiency of the compressor.

9. The device used to operate a compressor, independent of the system's controls, for troubleshooting is called a

   a. hermetic compressor analyzer.
   b. compressor test cord.
   c. volt-ammeter.
   d. wattmeter.

10. A small compressor used in a domestic refrigeration system will have a volumetric efficiency between

    a. 30 and 70 percent.
    b. 40 and 75 percent.
    c. 50 and 80 percent.
    d. 60 and 85 percent.

Operation of Metering Devices

UNIT OBJECTIVE

Upon completion of this unit, you will be able to describe the operation, and choose the correct capacity of three metering devices by using each in the exercises.

DISCUSSION OUTLINE

The Discussion of Fundamentals covers the following points:

- New terms and words
- Equipment required

DISCUSSION OF FUNDAMENTALS

A metering device is an essential element of any refrigeration system. It reduces high pressure liquid refrigerant to low pressure liquid refrigerant in the correct quantities to operate a system at maximum efficiency and without overloading the compressor.

There are three main types of refrigerant metering controls:

1. Automatic expansion valves

2. Thermostatic expansion valves

3. Capillary or choke tubes

These controls operate on 1) pressure changes 2) temperature changes 3) volume changes or 4) any combination of these.

A metering device in a refrigeration system is primarily a restriction between the high and low sides of the system. This restriction enables the compressor to maintain a pressure difference between the two sides of the system. Refrigerant flows back from the high side to the low side at a controlled rate. The rate of refrigerant flow through the restriction (metering device) must be adequately matched with the pumping capacity of the compressor. This is required to maintain the low pressure in the evaporator for boiling of the refrigerant, and to maintain the high pressure in the condenser for proper heat rejection and condensation of the refrigerant vapor.

New terms and words

Automatic expansion valve – a pressure-controlled valve which reduces high-pressure liquid refrigerant to low-pressure liquid refrigerant.

Diaphragm – a flexible material usually made of thin metal, rubber or plastic, which flexes with variations of pressure on both sides.

Flash – instantaneous evaporation of some liquid refrigerant in an evaporator which cools the remaining liquid refrigerant to the desired evaporation temperature.

Superheat – the temperature difference of refrigerant vapor above the saturation temperature (boiling point) corresponding to its pressure. Measured as the difference between the temperature at the evaporator outlet and the lower temperature of the refrigerant evaporating in the evaporator.

Thermal element – part of a sealed fluid device which reacts to temperature and is used to control a thermostatic expansion device.

Thermostatic expansion valve – control valve operated by temperature and pressure within the evaporator. It controls flow of refrigerant into evaporator according to a preset superheat level.

Equipment required

- Refrigeration System Trainer, Model 3401

Thermostatic Expansion Valve

Exercise Objective

When you have completed this exercise, you will be able to describe the operation of a **thermostatic expansion valve** by using one in the exercise.

Discussion Outline

The Discussion of this exercise covers the following points:

- Operation
- Capacity

Discussion

The thermostatic expansion valve (TEV), as shown in Figure 4-1, is used for refrigerant flow control and operates at varying pressures resulting from varying temperatures. This valve maintains constant superheat in the evaporator.

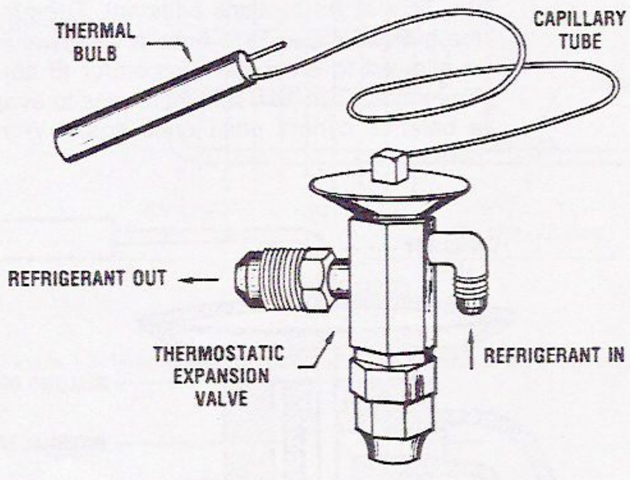


Figure 4-1. Thermostatic expansion valve.

Operation

The thermostatic expansion valve requires the aid of a capillary tube and thermal element (bulb) to operate. The element is partly filled with a liquid refrigerant (usually the same refrigerant used in the system) and maintains some liquid under all conditions of temperature and load. A cross-section view of a thermostatic expansion valve with the principle components identified is shown in Figure 4-2.

The three forces which govern the operation of the thermostatic expansion valve are:

- **P1**: The vapor pressure of the thermostatic element (a reaction to the bulb temperature) which acts to open the valve.
- **P2**: The evaporator pressure which acts in a closing direction below the diaphragm.
- **P3**: The pressure equivalent of the superheat spring force which is also applied underneath the diaphragm in a closing force.

At any constant operating condition, these forces are balanced. Therefore,

$$P1 = P2 + P3$$

When a change in temperature in the suction line occurs, the pressure in the thermal bulb also changes correspondingly. With an increased heat load, the refrigerant in the evaporator boils away faster. This results in a rise in temperature at the thermal bulb due to superheating. The higher temperature produces an increase in pressure within the thermal bulb which increases the pressure at P1. The pressure in the evaporator at P2, and the spring pressure in the TEV at P3 remains constant. Therefore, with the increased pressure at P1, the bellows expands to force a wider valve opening. As a result, more refrigerant is allowed to enter the evaporator to compensate for the increased heat load. The increase in flow rate increases to evaporator pressure P2, which establishes a balance control point once again. With a decreased load the reverse cycle takes place.

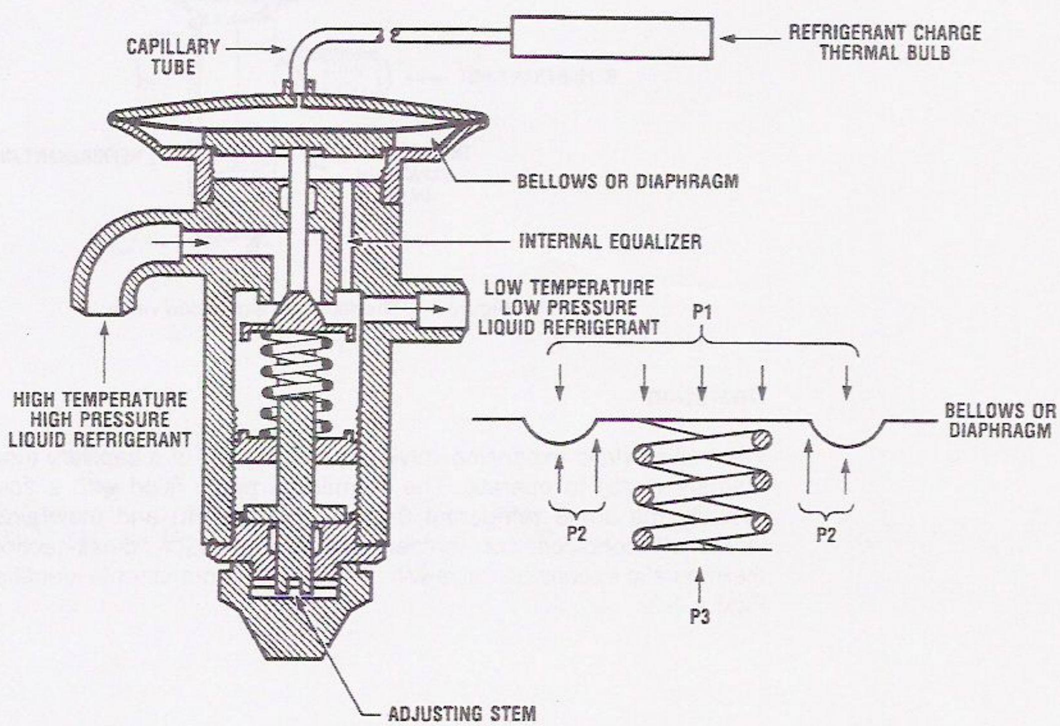


Figure 4-2. Cross-section view of the internal construction of a thermostatic expansion valve.

The evaporator shown in Figure 4-3 operates on a typical refrigerant at a saturation temperature of −5.6°C (22°F) with a pressure of 155 kPa (22.4 psi). When liquid refrigerant enters the expansion valve, the pressure and temperature are reduced at the valve port. The refrigerant then enters the evaporator at point A as a mixture of saturated liquid and vapor. As flow continues through the evaporator, the boiling refrigerant gradually evaporates. The temperature of the refrigerant will remain at 5.6°C (22°F), assuming no pressure drop, until the liquid portion is completely evaporated by the absorption of heat (point B). From this point, additional heat absorption increases the temperature and superheats the refrigerant vapor.

The pressure remains at 155 kPa (22.4 psi) until point C, where the refrigerant and vapor temperature is 0°C (32°F). At this point, the superheat is 0°C minus −5.6°C (32°F minus 22°F) or 5.6°C (10°F).

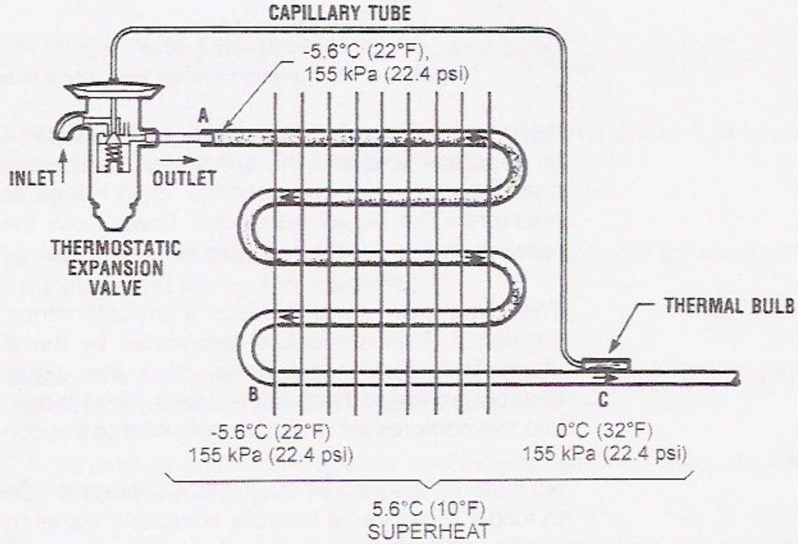


Figure 4-3. Thermostatic expansion valve control of an evaporator.

Capacity

The capacity of a thermostatic expansion valve differs due to orifice size, pressure difference between high and low side, and the temperature and condition of the refrigerant in the liquid line. The amount of liquid that will flash to a vapor will increase with a rise in liquid line temperature. The capacity of most valves, however, may be determined by the orifice size and needle assembly. The body size remains the same for many capacities.

Thermostatic expansion valves are rated in tons of refrigeration. However, three different tonnage capacities are usually provided for the same orifice. The range of capacity depends upon the difference in pressure between the high and the low sides of the system.

Using the appropriate capacity valve is very important. If the valve orifice is too small, the evaporator will be starved regardless of the superheat setting. The full capacity of the evaporator will never be obtained. If the valve orifice is oversized, too much refrigerant will pass into the evaporator and the suction line will sweat or frost before the thermal element can close the valve.

The schematic diagram shown in Figure 4-4 is a typical refrigeration system using a thermostatic expansion valve as the metering device. Temperature and pressure sensing points are located on the schematic to indicate where measurements should be taken.

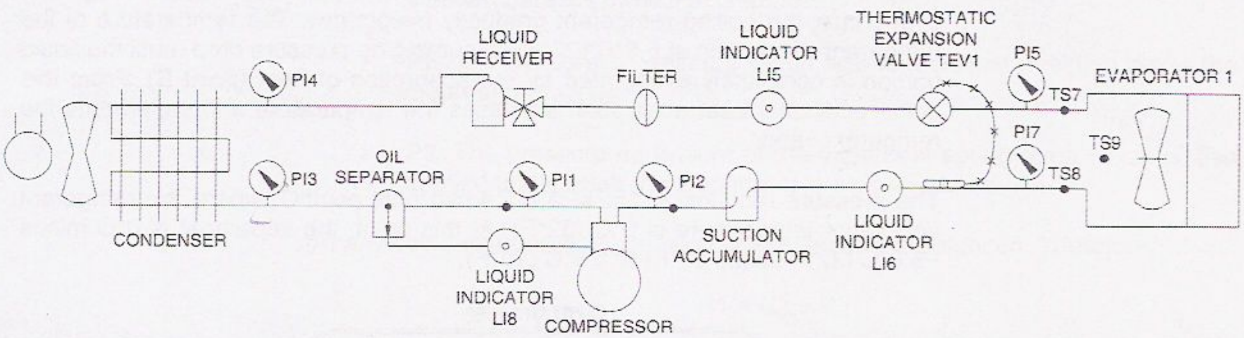


Figure 4-4. Refrigeration system with thermostatic expansion valve control.

A high pressure refrigerant vapor is discharged from the compressor through an oil separator and into the condenser. In the condenser, heat is given off which changes the refrigerant vapor to liquid refrigerant at the same temperature and pressure. The liquid refrigerant flows from the condenser through the liquid receiver and to the thermostatic expansion valve.

The expansion valve permits a predetermined amount of refrigerant to flow through it. This amount is determined by the thermal bulb at the outlet of the evaporator. Refrigerant flows from the expansion device and through the evaporator where heat is absorbed. Heat laden refrigerant vapor is then drawn into the compressor and compressed into the condenser.

No pictorial diagram of the system will be provided in this exercise or in exercises to follow. However, a trainer's schematic panel (tubing section) showing the valve configuration for each exercise will be provided at the back of the manual in Appendix A, to assist the student.

Procedure Outline

The Procedure is divided into the following sections:

- Thermostatic expansion valve

Procedure

Thermostatic expansion valve

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 4-4. Figure A-1 in Appendix A may be used to assist in the proper set-up of the system.

   Place the evaporator cabinet divider (located at the top of the two evaporator cabinet) in the up position in order to isolate evaporator 1 from evaporator 2. (A sliding bolt mechanism is used to lock the cabinet divider into place).

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
V5	V1		V17	V7	
V24	V11		V18	V9	
V16	V12		V6		
V3	V8		V15		
V2			V4		
V14			V13		
V21			V22		
V23			V10		

3. Turn on the mains input breaker switch.

4. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to maximum.

5. Start up the compressor and allow the trainer to operate for approximately 30 minutes to let the system stabilize.

6. Measure the pressures and temperatures listed in Table 4-1 and record your results in the column "WITHOUT HEAT LOAD".

All pressure and temperature test point locations are indicated on the diagrams in Figure 4-4 and Figure A-1.

If your set of temperature probes includes clamp-on probes, it is recommended that you use these probes for temperature measurements at the inlet and outlet of evaporator 1 to ensure a good accuracy of measurement. Also, if your set of probes includes an air (coiled) probe, this probe can be used to measure the temperature within the evaporator's cabinet.

Table 4-1. Pressure and temperature measurements with and without the heat load.

System measurements		Without heat load	With heat load
Pressure	Compressor suction (PI2)	14	14
	Compressor discharge (PI1)	115	120
	Condenser inlet (PI3)	115	120
	Condenser outlet (PI4)	115	120
	Evaporator-1 inlet (PI5)	18	20
	Evaporator-1 outlet (PI7)	15	16
Temperature	Evaporator-1 inlet (TS7)	19,8	21
	Evaporator-1 cabinet (TS9)	29,5	43
	Evaporator-1 outlet (TS8)	16,5	24
Superheat			

7. From the results recorded in Table 4-1, calculate the superheat of the saturated vapor at the evaporator outlet, using the steps below.

   a. First, find the saturation temperature corresponding to the evaporator-1 outlet pressure measured at PI7.

   To do so, use the pressure-temperature (P/T) chart in Appendix F of the manual. For example, if the evaporator outlet pressure is 83 kPa (12 psi), the corresponding saturation temperature, for R-134a refrigerant, is −12.2°C (10°F).

   Saturation temperature: 9,4 °C or 15 °F

   b. Calculate the superheat by subtracting this saturation temperature from the evaporator-1 outlet temperature measured at TS8.

   Superheat = Saturation. temp. − TS8 temp. = −16,9 °C or 1.5 °F

   Record this superheat in the column "WITHOUT HEAT LOAD" of Table 4-1.

8. Increase the heat load on evaporator 1: turn on the heat load breaker switch (on the control panel located on the right-hand side of the trainer).

   Allow the trainer to operate for approximately 30 minutes to let the system stabilize.

9. Fill in the remainder of Table 4-1 by measuring the listed pressures and temperatures, recording your results in the column "WITH HEAT LOAD".

10. From the results recorded in the column 'WITH HEAT LOAD" of Table 4-1, calculate the superheat of the saturated vapor at the evaporator outlet, when the heat load is applied.

    a. First, find the saturation temperature corresponding to the evaporator-1 outlet pressure measured at PI7.

       Saturation temperature: -8.8 °C or 16 °F

    b. Calculate the superheat by subtracting this saturation temperature from the evaporator outlet temperature measured at TS8.

       Superheat = Saturation temp. − TS8 temp. = -13.2 °C or 8.2 °F

    Record this superheat in the column "WITH HEAT LOAD" of Table 4-1.

11. Turn off the heat load breaker switch. Turn off the condenser and evaporator fans.

12. Turn off the compressor and main breaker switch.

13. Based on the data recorded in Table 4-1, describe the effect that the increase in heat load had on the temperature in the evaporator-1 cabinet (TS9).

    Heat load increased temp in evap cab.

    You should observe that the evaporator-1 cabinet temperature increases when the heat load is applied. However, a temperature difference is maintained across the evaporator inlet and outlet, allowing the cabinet to be properly refrigerated.

14. By filling in the blanks below, describe the effect that the increase in heat load on evaporator 1 had on the inlet and outlet temperatures and pressures (TS7, TS8, PI5, and PI7) of this evaporator.

    The increased heat load on evaporator 1 caused the refrigerant to pick up more (more/less) heat as it passed through the evaporator coils. The thermal bulb of thermostatic expansion valve TEV1 sensed this increase (increase/decrease) in refrigerant temperature, which resulted in increase (increased/decreased) pressure on top of the valve diaphragm. This caused the valve orifice to increase (increase/decrease) in size and thus increase the amount of refrigerant entering the evaporator. This was indicated by the increase (increased/decreased) temperatures and pressures at the evaporator-1 inlet and outlet.

15. Based on the data recorded in Table 4-1, did the increase in heat load have little, if no significant effect on the superheat? Explain.

16. Did the increase in heat load cause the pressure difference (PI1 – PI2) across the compressor to increase? Explain.

CONCLUSION

The thermostatic expansion valve operates at varying pressures resulting from varying temperatures at the suction line. This valve maintains a constant superheat in the evaporator. When the heat load in the refrigerated area increases, the valve opens wider, allowing more refrigerant to flow into the evaporator to compensate for the increased load. Conversely, if the load decreases the valve allows less refrigerant to flow into the evaporator. The valve must be sized correctly to ensure maximum system efficiency.

REVIEW QUESTIONS

1. What is the purpose of a thermostatic expansion valve (TEV) and what are the load conditions under which it is ideally used?

The TEV maintains a constant superheat. It operates at various pressures and temperatures

2. Explain the operation of the thermostatic expansion valve (TEV) in relation to forces P1, P2, and P3.

When temperature in the suction line increases, thermal bulb temperature and pressure also increases, this causes ~~P~~ to push down on bellows/diaphragm. The pressure of P2 ~~&~~ P3 will remain constant during this, allowing the valve to open.

3. Explain how the capacity of the TEV is determined for any particular load conditions.

Capacity of TEV is determined by the orifice size, pressure differences between ~~the~~ high and low sides, as well as the condition and temperature of the refrigerant in liquid line.

4. What problems may arise if the TEV capacity is incorrect for a particular refrigeration system?

If the TEV orifice is too small the evaporator will be starved for refrigerant. If it's too big the evaporator will sweat or frost up.

5. Where is the thermal bulb of a thermostatic expansion valve located on a refrigeration system? Explain why.

It's located at the evaporator outlet. This is because the TEV needs to sense the suction line temperature to determine how much refrigerant it can allow through.

Automatic Expansion Valve

Exercise Objective

When you have completed this exercise, you will be able to explain the operation of an **automatic expansion valve** by using one in the exercise.

Discussion Outline

The Discussion of this exercise covers the following points:

- Operation
- Selection
- Application

Discussion

The automatic expansion valve (AEV), shown in Figure 4-5, is also called a constant pressure expansion valve. This valve automatically adjusts the flow of liquid refrigerant to the evaporator to balance the compressor pumping capacity.

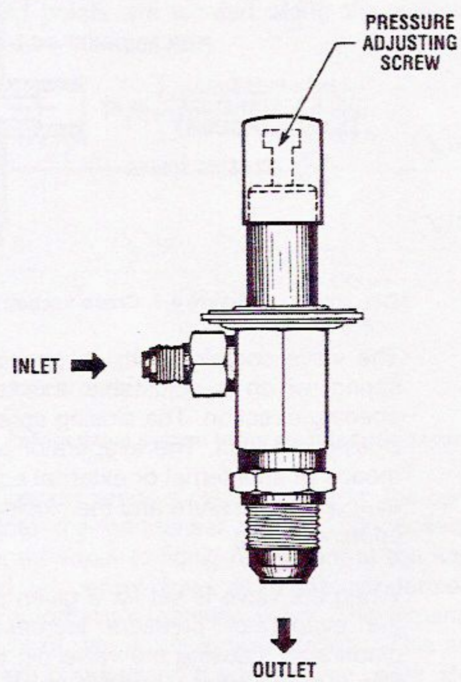


Figure 4-5. Automatic expansion valve.

Operation

The automatic expansion valve is operated by the evaporator pressure. The valve regulates the mass flow rate of liquid refrigerant entering the evaporator and thereby maintains the evaporator pressure at a constant value. With the evaporator pressure kept constant, the suction pressure at the compressor also remains constant. This type of metering device is used in refrigeration systems where the refrigeration capacity of the compressor remains constant, such as in a water fountain.

A cross-section view of the automatic expansion valve is shown in Figure 4-6.

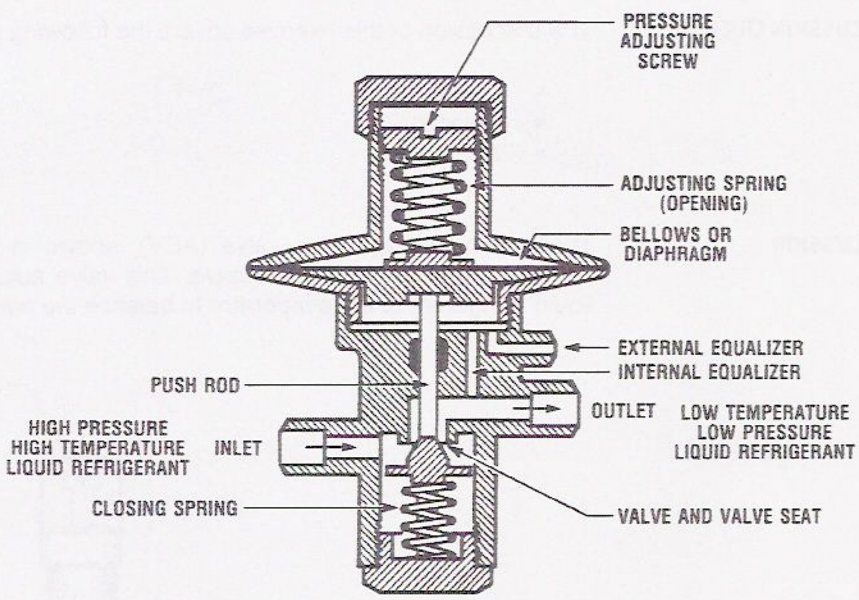


Figure 4-6. Cross-section view of an automatic expansion valve.

The valve contains both an opening spring and a closing spring. The opening spring, which is adjustable, exerts a force on the top of the diaphragm in an opening direction. The closing spring, exerts a force beneath the diaphragm in a closing direction. The evaporator pressure is exerted beneath the diaphragm by means of an internal or external equalizing passage. The combined forces of the evaporator pressure and the closing spring act to counterbalance the force of the opening spring.

When the valve is set for a given pressure and a small increase in load occurs, the evaporator pressure increases. This increases the force beneath the diaphragm, causing the valve pin to move in a closing direction. The refrigerant flow is then further restricted which limits the evaporator pressure.

Conversely, when a decrease in load occurs, the evaporator pressure drops below the valve setting. The top spring pressure then moves the valve pin in an opening direction. This increases the refrigerant flow in an effort to raise the evaporator pressure to balance the valve setting.

Selection

The automatic expansion valve, for liquid expansion service, should be selected for the required capacity and system refrigerant at the lowest expected pressure drop across the valve. The valve should also have an adjustable pressure range to provide the required evaporator (valve outlet) pressure.

Application

The automatic expansion valve, when applied as a liquid refrigerant expansion valve, is suitable only for constant load applications. Its use is therefore limited.

When used on a variable load application, this valve starves the evaporator at the high load and overfeeds it at the low load with possible compressor damage resulting.

Applications suitable for automatic expansion valves are drink dispensers, food dispensers, water coolers, ice cream freezers, and self-contained room air conditioning systems.

The schematic diagram shown in Figure 4-7 is a typical refrigeration system using an automatic expansion valve (AEV1) as the metering device. Temperature and pressure sensing points are located along the system to indicate where measurements should be taken.

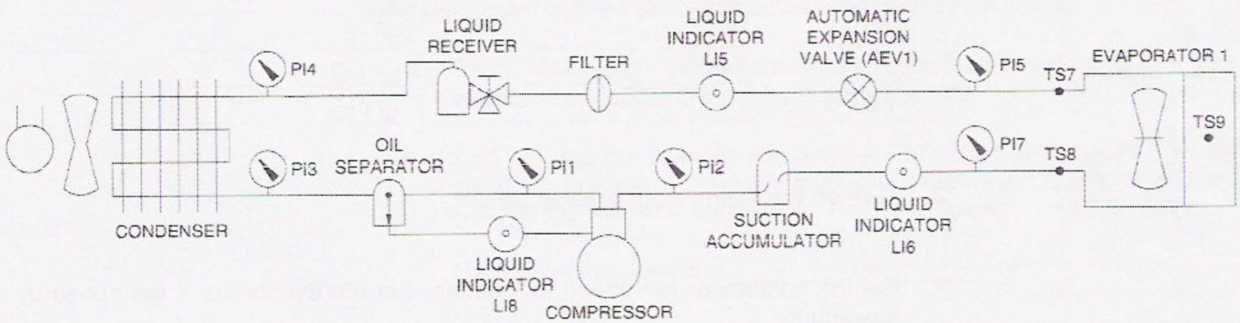


Figure 4-7. Refrigeration system using an automatic expansion valve.

A high pressure refrigerant vapor is discharged from the compressor through an oil separator and into the condenser. In the condenser, heat is given off, changing the refrigerant vapor to liquid refrigerant at the same temperature and pressure. The liquid refrigerant flows from the condenser through the liquid receiver and to the automatic expansion valve. The expansion valve permits a predetermined amount of refrigerant to flow through. This amount is determined by the evaporator back pressure on the expansion valve. Refrigerant flows from the expansion device and through the evaporator where heat is absorbed and taken to the compressor.

The use of a suction line accumulator is highly recommended to prevent any non-vaporized (liquid) refrigerant exiting an overfed (flooded) evaporator from reaching the compressor inlet.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Automatic expansion valve

PROCEDURE

Automatic expansion valve

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 4-7. Figure A-2 in Appendix A may be used to assist in the proper set-up of the system.

   Make sure the evaporator cabinet divider (located at the top of the two evaporator cabinets) is in the up position in order for evaporator 1 to be isolated from evaporator 2.

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
V5	V1		V16	V15	
V24	V11		V18	V22	
V17	V12		V4		
V3	V8		V6		
V2			V7		
V14			V9		
V21			V10		
V23			V13		

3. Turn on the mains input breaker switch.

4. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to maximum.

5. Start up the compressor and allow the trainer to operate for approximately 30 minutes to let the system stabilize.

6. Measure the pressures and temperatures listed in Table 4-2 and record your results in the column "WITHOUT HEAT LOAD".

   All pressure and temperature test point locations are indicated on the diagrams in Figure 4-7 and Figure A-2.

   If your set of temperature probes includes clamp-on probes, it is recommended that you use these probes for temperature measurements at the inlet and outlet of evaporator 1 to ensure a good accuracy of measurement. Also, if your set of probes includes an air (coiled) probe, this probe can be used to measure the temperature within the evaporator's cabinet.

Table 4-2. Pressure and temperature measurements with and without the heat load.

System measurements		Without heat load	With heat load
Pressure	Compressor suction (PI2)	22	25
	Compressor discharge (PI1)	125	125
	Condenser inlet (PI3)	110	110
	Condenser outlet (PI4)	110	115
	Evaporator-1 inlet (PI5)	26	28
	Evaporator-1 outlet (PI7)	24	26
Temperature	Evaporator-1 inlet (TS7)	29.6	33
	Evaporator-1 cabinet (TS9)	39.[illegible]	43
	Evaporator-1 outlet (TS8)	29	32
Superheat			

7. From the results recorded in Table 4-2, calculate the superheat of the saturated vapor at the evaporator outlet, using the steps below.

   a. First, find the saturation temperature corresponding to the evaporator-1 outlet pressure measured at PI7.

   To do so, use the pressure-temperature (P/T) chart in Appendix F of the manual. For example, if the evaporator outlet pressure is 138 kPa (20 psi), the corresponding saturation pressure, for R-134a refrigerant, is −5.6°C (22°F).

   Saturation temperature: ______ °C or ______ °F

   b. Calculate the superheat by subtracting this saturation temperature from the evaporator-1 outlet temperature measured at TS8.

   Superheat = Saturation temp. − TS8 temp. ______ °C ______ °F

   Record this superheat in the column "WITHOUT HEAT LOAD" of Table 4-2.

8. Increase the heat load on the system: turn on the heat load breaker switch (on the control panel located on the right-hand side of the trainer).

   Allow the trainer to operate for approximately 30 minutes to let the system stabilize.

9. Fill in the remainder of Table 4-2 by measuring the listed pressures and temperatures, recording your results in the column "WITH HEAT LOAD".

10. From the results recorded in the column 'WITH HEAT LOAD" of Table 4-2, calculate the superheat of the saturated vapor at the evaporator outlet, when the heat load is applied.

    a. First, find the saturation temperature corresponding to the evaporator-1 outlet pressure measured at PI7.

       Saturation temperature: _______ °C or ___30___ °F

    b. Calculate the superheat by subtracting this saturation temperature from the evaporator outlet temperature measured at TS8.

       Superheat = Saturation temp. − TS8 temp. = _______ °C or ___2___ °F

    Record this superheat in the column "WITH HEAT LOAD" of Table 4-2.

11. Turn off the heat load breaker switch. Turn off the condenser and evaporator fans.

12. Turn off the compressor and main breaker switch.

13. Based on the data recorded in Table 4-2, describe the effect that the increase in heat load had on the evaporator-1 inlet, cabinet, and outlet temperatures (TS7, TS9, and TS8).

    It increased all of their temperatures

    You should observe that the evaporator-1 cabinet temperature increases when the heat load is applied. However, a temperature difference is maintained across the evaporator inlet and outlet, allowing the cabinet to be properly refrigerated.

14. In Table 4-2, observe that the increase in heat load on evaporator 1 resulted in a somewhat low increase in evaporator inlet pressure (PI5).

    This occurred because when an increase in heat load occurs, the evaporator inlet pressure ___increase___ (increases/decreases). This causes the force beneath the diaphragm of valve AEV1 to ___increase___ (increase/decrease), causing the valve pin to move in a(n) ___closing___ (opening/closing) direction, so as to ___restrict___ (increase/restrict) the refrigerant flow to evaporator 1 and, therefore, limit the increase in evaporator inlet pressure.

15. Compare the compressor suction and discharge pressures (PI2 and PI1) recorded in Table 4-2 without and with the heat load. Then, fill in the blanks.

    When the heat load on evaporator 1 is increased, the compressor suction pressure ________________ (increases/decreases) slightly. However, the compressor discharge pressure ________________ (increases/decreases/ stays approximately the same) since it takes a large suction pressure change to produce a small discharge pressure variation.

16. Based on the data recorded in Table 4-2, did the increase in heat load have little, if any significant effect on the superheat? Explain.

    ____

    ____

17. In this exercise, you increased the heat load on evaporator 1. If the heat load on this evaporator were decreased (for example, by decreasing the evaporator-1 fan speed), the evaporator inlet pressure would ________________ (increase/decrease) below the valve pressure setting. This would cause the valve pin to move in a(n) ________________ (opening/closing) direction to increase the refrigerant flow to evaporator 1 and limit the decrease in evaporator inlet pressure.

    It is important to keep in mind that if the heat load on evaporator 1 is decreased too much (by, for example, decreasing the evaporator fan speed too much), the valve will throttle wide open to let more refrigerant flow to the evaporator in an attempt to raise the evaporator inlet pressure, causing the evaporator to become over fed (flooded). This will be indicated by maintained low evaporator inlet and outlet pressures and temperatures, since the amount of heat available for absorption by the refrigerant is insufficient to permit a proper superheat.

    If the heat load is decreased even further, frosting of the evaporator will result, and excessive liquid refrigerant will flow out of the evaporator. In the absence of the suction line accumulator to collect the liquid refrigerant in excess, this might cause damage to the compressor.

18. Based on what you have learned, compare the operation of an automatic expansion valve to that of a thermostatic expansion valve:

    The operation of an automatic expansion valve is ________________ (the same as/opposite to) that of the thermostatic expansion valve. This is due to the constant pressure regulating property of the automatic expansion valve. With increased load on the evaporator, the automatic valve must ________________ (open/close) to limit the pressure in the evaporator. On the other hand, the thermostatic valve must ________________ (open/close) under the same conditions to decrease the superheat level to its normal value.

Conclusion

The automatic expansion valve is used in refrigeration systems where evaporator loading is relatively constant. These valves automatically adjust the flow of liquid refrigerant to the evaporator, thus minimizing pressure fluctuations in the suction line and maintaining a nearly constant pumping capacity of the compressor.

Review Questions

1. What kind of load conditions must exist in the refrigeration system in order to warrant the use of an automatic expansion valve?

   A constant refrigeration capacity/load would make use of an AEV.

2. Where is an automatic expansion valve located in a refrigeration system?

   It's located between the condensor and evaporator.

3. Briefly describe the operation of an automatic expansion valve as the evaporator pressure increases and decreases.

   When the evaporator pressure increases the AEV diaphragm will close, limiting the flow of refrigerant to the evaporator which will cause the superheat to increase

4. How is an automatic expansion valve selected for use in any particular refrigeration system?

   The system in question must have constant ~~[illegible]~~ load, be the right refrigerant, and be fitted for the lowest pressure drop.

5. How does the operation of an automatic expansion valve differ from that of a thermostatic expansion valve? (Refer to Exercise 4-1).

   An AEV has 2 springs, isn't designed for changing/dynamic loads and operates at a constant pressure. TXV is designed for a constant superheat under dynamic loads

adiabatic – no change in enthalpy

Capillary Tube

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to explain the principles of operation of a capillary tube control by using one in the exercise.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Operation
- System Design Factors

DISCUSSION

A capillary tube, as shown in Figure 4-8, is a common type of refrigerant control. The capillary is simply a length of tubing with a small inside diameter which acts as a constant throttle on the refrigerant entering the evaporator.

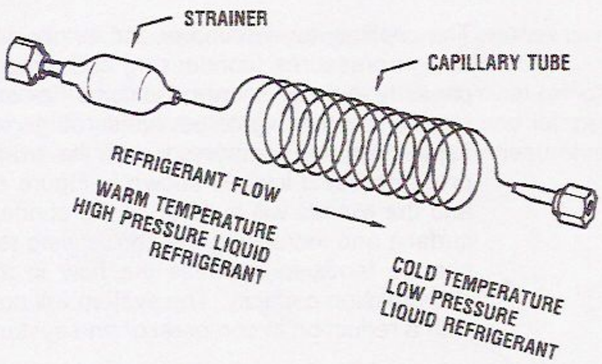


Figure 4-8. Capillary tube control.

A fine filter or filter drier installed at the inlet of the capillary prevents dirt from blocking the tube.

Recent developments in the design of capillary tubes for air conditioning systems uses capillary tubes with a larger inside diameter and a longer tube length. A larger diameter tube is less likely to become plugged with dirt and other impurities than a smaller diameter tube. The longer length provides the necessary resistance to create the desired pressure differential across the metering device.

The capillary tube equalizes the pressures in the system when the unit stops. This pressure equalizing characteristic of the capillary allows a low starting torque motor to be used with the compressor. Typically, a capillary does not operate as efficiently over a wide range of conditions as does the thermostatic expansion valve. However, because of its counterbalance factors in most applications, its performance is generally very good.

Refrigeration systems using a capillary tube do not require the use of a liquid receiver since all the liquid is stored in the evaporator during the off cycle. However, a suction accumulator is often found in the suction line to prevent any non-vaporized refrigerant from reaching the compressor. This will prevent damage to the compressor when excessive liquid refrigerant enters the evaporator on a low evaporator load condition.

Operation

The capillary tube can be described as a fixed length of small bore tubing connecting the high pressure side (condenser) of a refrigeration system to the low pressure side (evaporator). By restricting and metering the liquid flow, the capillary tube can maintain the required pressure differential between the condenser and the evaporator. Because of friction and acceleration, the pressure drops as the liquid flows through the tube. In order to reduce the temperature of the liquid to the saturation temperature of the evaporator, some of the liquid must turn into a vapor, ("flash") in the capillary tube, just as it does with all refrigerant controls.

System Design Factors

The capillary tube diameter and length must be such that the flow capacity at the design pressures (condensing and evaporating) equal the compressor pumping capacity at these same conditions. For example, if the tube diameter is too small (resistance too high) the liquid refrigerant flow will be less than the pumping capacity of the compressor with the evaporator being "starved" and the suction pressure being low, as shown in Figure 4-9. Less liquid will enter the evaporator and the excess will build up in the condenser, reducing the effective condensing surface and increasing the condensing temperature and pressure. This pressure change tends to increase the flow in the tube and at the same time reduce compression capacity. The system will now balance at other than design capacity with a reduction in compressor and system capacity.

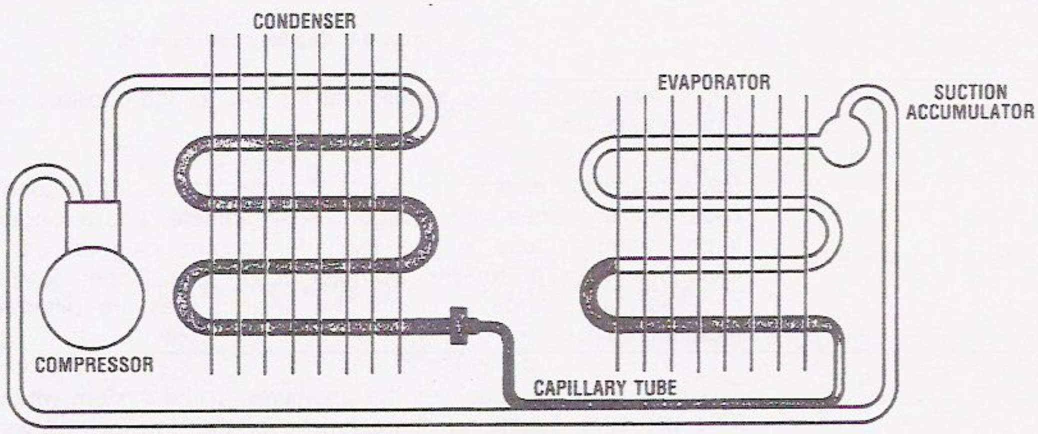


Figure 4-9. Refrigeration system with capillary resistance that is too high, resulting in a starved evaporator.

If the capillary tube resistance to the refrigerant flow is too low, (diameter of tube too large), the flow rate will be greater than pumping capacity. This results in the

flooding or overfeeding of the evaporator, and flood back of liquid to the compressor if there is no suction accumulator in the compressor suction line.

The refrigeration system shown in Figure 4-10 uses a capillary tube selected for capacity balanced conditions. A liquid seal is present at the capillary inlet but no excess liquid in the condenser. The compressor discharge and suction pressures are normal and the evaporator is properly charged.

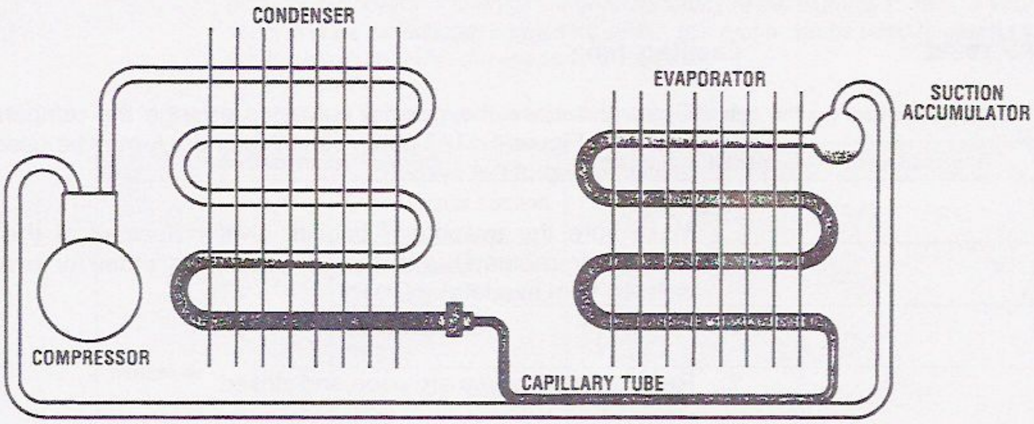


Figure 4-10. Balanced refrigeration system using capillary tube.

The schematic diagram as shown in Figure 4-11 is a typical refrigeration system using a capillary tube as the metering device. Pressure and temperature sensing points are located on the schematic to indicate where measurements should be taken.

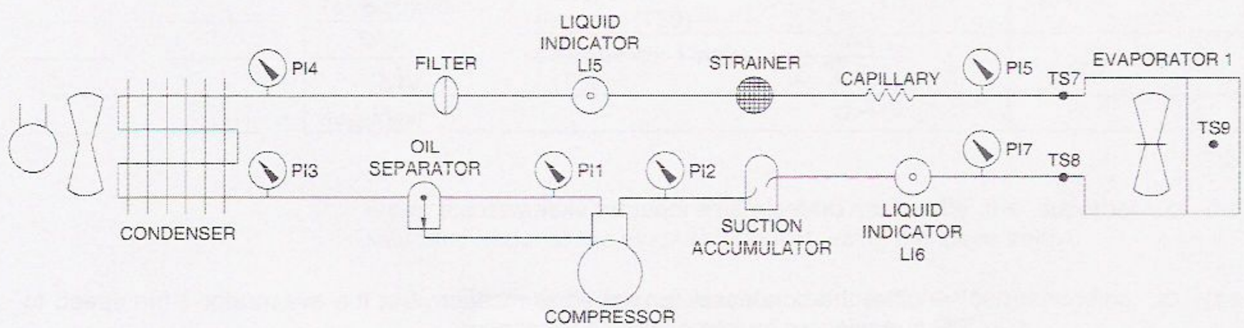


Figure 4-11. Refrigeration system with capillary tube control.

A high pressure refrigerant vapor is discharged from the compressor through an oil separator and into the condenser. In the condenser, heat is given off, changing the refrigerant vapor to liquid refrigerant at the same temperature and pressure. The liquid refrigerant flows from the condenser through the filter drier and to the capillary tube.

The capillary tube permits a predetermined amount of refrigerant to flow through. This amount is determined by the internal diameter and length of the tube and also the system capacity.

Refrigerant flows from the capillary tube and through the evaporator where heat is absorbed and removed. The refrigerant passes through a suction accumulator

to collect liquid refrigerant which has not vaporized and flows back to the compressor.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Capillary tube

PROCEDURE

Capillary tube

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 4-11. Figure A-3 in Appendix A may be used to assist in the proper set-up of the system.

   Make sure the evaporator cabinet divider (located at the top of the two evaporator cabinets) is in the up position in order for evaporator 1 to be isolated from evaporator 2.

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
V5	V11		V16	V15	
V24	V1		V17	V22	
V18	V12		V4		
V3	V8		V6		
V2			V7		
V14			V9		
V21			V10.		
V23			V13		

3. Turn on the mains input breaker switch.

4. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to maximum.

5. Start up the compressor and allow the trainer to operate for approximately 30 minutes to let the system stabilize.

6. Measure the pressures and temperatures listed in Table 4-3 and record your results in the column "WITHOUT HEAT LOAD".

All pressure and temperature test point locations are indicated on the diagrams in Figure 4-11 and Figure A-3.

If your set of temperature probes includes clamp-on probes, it is recommended that you use these probes for temperature measurements at the inlet and outlet of evaporator 1 to ensure a good accuracy of measurement. Also, if your set of probes includes an air (coiled) probe, this probe can be used to measure the temperature within the evaporator's cabinet.

Table 4-3. Pressure and temperature measurements with and without the heat load.

System measurements		Without heat load	With heat load
Pressure	Compressor suction (PI2)	~~24~~ 22	241
	Compressor discharge (PI1)	135	135
	Condenser inlet (PI3)	120	125
	Condenser outlet (PI4)	120	125
	Evaporator-1 inlet (PI5)	25	27
	Evaporator-1 outlet (PI7)	22	25
Temperature	Evaporator-1 inlet (TS7)	29	32
	Evaporator-1 cabinet (TS9)	39	43
	Evaporator-1 outlet (TS8)	28	30
Superheat			

7. From the results recorded in Table 4-3, calculate the superheat of the saturated vapor at the evaporator outlet, using the steps below.

   a. First, find the saturation temperature corresponding to the evaporator-1 outlet pressure measured at PI7.

   To do so, use the pressure-temperature (P/T) chart in Appendix F of the manual. For example, if the evaporator outlet pressure is 138 kPa (20 psi), the corresponding saturation temperature, for R-134a refrigerant, is −5.6°C (22°F).

   Saturation temperature: _______ °C or _______ °F

   b. Calculate the superheat by subtracting this saturation temperature from the evaporator-1 outlet temperature measured at TS8.

   Superheat = Saturation temp. − TS8 temp. = ______ °C or _______ °F

Record this superheat in the column "WITHOUT HEAT LOAD" of Table 4-3.

8. Increase the heat load on the system: turn on the heat load breaker switch (on the control panel located on the right-hand side of the trainer).

   Allow the trainer to operate for approximately 30 minutes to let the system stabilize.

9. Fill in the remainder of Table 4-3 by measuring the listed pressures and temperatures, recording your results in the column "WITH HEAT LOAD".

10. From the results recorded in the column 'WITH HEAT LOAD" of Table 4-3, calculate the superheat of the saturated vapor at the evaporator outlet, when the heat load is applied.

    a. First, find the saturation temperature corresponding to the evaporator-1 outlet pressure measured at PI7.

       Saturation temperature: _______ °C or _______ °F

    b. Calculate the superheat by subtracting this saturation temperature from the evaporator outlet temperature measured at TS8.

       Superheat = Saturation temp. − TS8 temp. = ______ °C or ______ °F

    Record this superheat in the column "WITH HEAT LOAD" of Table 4-3.

11. Turn off the heat load breaker switch. Turn off the condenser and evaporator fans.

12. Turn off the compressor and main breaker switch.

13. Based on the data recorded in Table 4-3, describe the effect that the increase in heat load had on the evaporator-1 inlet, cabinet, and outlet temperatures (TS7, TS9, and TS8).

    ____

    ____

    You should observe that the evaporator-1 cabinet temperature increases when the heat load is applied. A temperature difference—though quite small—exists across the evaporator inlet and outlet, permitting proper refrigeration of the cabinet.

14. Based on the data recorded in Table 4-3, calculate the pressure differential, ΔP, across the capillary tube without and with the heat load applied.

    ΔP = Condenser outlet pressure (PI4) − Evaporator inlet pressure (PI5)

    ΔP without heat load = ______ kPa or ______ psi

    ΔP with heat load applied = ______ kPa or ______ psi

    According to your results, did the ΔP across the capillary tube increase when the heat load was applied?

    ❑ Yes ❑ No

15. Fill in the blanks below, referring to Table 4-3 if necessary.

    When the heat load on evaporator 1 is increased, the size of the capillary-tube restriction for refrigerant ______________ (increases/decreases/ stays the same). This occurs because the capillary tube does not have a feedback characteristic that permits **direct control** of the refrigerant flow to evaporator 1.

    However, the increase in heat load causes the compressor suction side pressure to ______________ (increase/decrease), resulting in a ______________ (higher/lower) compressor discharge pressure. Therefore, there is an overall ______________ (increase/decrease) in the pressure differential across the capillary which increases the refrigerant flow to evaporator 1.

    This overall feedback characteristic, however, is limited: it does not provide sufficient flow compensation under all conditions, so that flooding of evaporator 1 will result if the heat load on the system is decreased significantly. Under low evaporator-1 fan speed, for example, flooding of the evaporator can occur: this will be indicated by extensive frosting of the suction line, decreasing evaporator cabinet temperature, and little difference between the evaporator inlet and outlet temperatures. Large quantities of liquid refrigerant can be seen through liquid indicator LI6. In the absence of the suction line accumulator to collect the liquid refrigerant in excess, this might cause damage to the compressor.

16. Did the increase in heat load have little effect on the superheat? Explain.

    ____

    ____

CONCLUSION

The capillary tube is a common type of refrigeration control, consisting of a length of tubing having a small inside diameter. This provides the restriction in the refrigeration system. The capillary tube provides a constant resistance to the flow of refrigerant from the high side to the low side of the system. When the heat load varies, the capillary tube allows, via compensation of the pressure drop by the compressor, to vary the refrigerant flow rate into the evaporator.

Review Questions

1. What is a capillary tube?

An expansion device with a coil of small diameter.

2. How does a capillary tube control the flow of refrigerant in a refrigeration system?

A capillary tube controls the flow of refrigerant by letting a fixed amount pass through its coil

3. What factors are involved when selecting the proper capillary tube control?

The capillary size must match the flow rate of condenser and evaporator as well as the pumping capacity of the compressor.

4. What will the effect be on a refrigeration system if too small a diameter of tubing is used for the capillary control?

If a small diameter capillary is used the evaporator won't get enough refrigerant and refrigerant will build up in the condenser, reducing compressor and system capacity

5. What will the effect be on a refrigeration system if too large a diameter of tubing is used for the capillary control?

If too large capillary is

Unit Test

1. The purpose of a refrigeration system metering device is to

   a. reduce high pressure refrigerant to low pressure refrigerant.
   b. maintain a pressure differential within a system.
   c. control the rate of flow of refrigerant into the evaporator.
   d. All of the above are correct.

2. When the temperature of the thermal bulb of a TEV increases, the valve opening will

   a. increase in size.
   b. decrease in size.
   c. increase and then decrease in size.
   d. remain the same.

3. After passing through the expansion valve, the refrigerant enters the evaporator as a

   a. vapor only.
   b. liquid only.
   c. liquid and vapor mixture.
   d. solid and liquid mixture.

4. A thermostatic expansion valve is set to maintain constant

   a. condenser pressure.
   b. condenser temperature.
   c. evaporator superheat.
   d. None of the above is correct.

5. An automatic expansion valve is used to maintain constant

   a. evaporator pressure.
   b. evaporator temperature.
   c. compressor suction pressure.
   d. All of the above are correct.

6. Under decreased evaporator load, the automatic expansion valve will

   a. decrease refrigerant flow.
   b. increase refrigerant flow.
   c. not affect refrigerant flow.
   d. shut off refrigerant flow completely.

7. An automatic expansion valve is ideally used on refrigeration systems with

   a. widely varying loads.
   b. moderately varying loads.
   c. slightly varying loads.
   d. constant loads.

8. A capillary tube control operates most effectively when the capillary tube has

   a. a smaller diameter and shorter length.
   b. a larger diameter and shorter length.
   c. a small diameter and longer length.
   d. a larger diameter and longer length.

9. A refrigeration system controlled by a capillary tube usually contains

   a. a suction accumulator.
   b. a liquid receiver.
   c. an oil separator.
   d. All of the above are correct.

10. A capillary tube control is ideally used on a refrigeration system with

    a. slightly varying loads.
    b. low compressor motor starting torque.
    c. constant compressor capacity.
    d. All of the above are correct.

System Control Devices

Unit Objective

Upon completion of this unit, you will be able to explain the operation of refrigeration system control devices, such as pressure controllers, temperature controllers, solenoid valve controls, and back pressure regulators.

Discussion Outline

The Discussion of Fundamentals covers the following points:

- New terms and words
- Equipment required

Discussion of Fundamentals

Refrigeration system controls refer to any device that starts, stops, regulates, and/or protects the refrigeration system and its components. These devices can be divided into three main classifications:

1. Operating or primary controls

2. Actuating or secondary controls

3. Limiting and safety controls

The operation of these control devices may be based on changes in temperature, pressure, volume, or **potential** (magnetic field).

Through the use of such controls, the required refrigeration system conditions may be maintained to ensure proper system operation.

In a refrigeration system, a low pressure condition is required on the suction side to maintain the desired rate of heat absorption through evaporation of liquid refrigerant. A high pressure condition must also be maintained on the high side to maintain the desired rate of heat dissipation through convection. At the same time, each component of the system must be protected from pressure and thermal overload.

Operating or primary controls are used to regulate changes in the desired system conditions, such as temperature or pressure. When the level of a desired condition begins to change, the controls will counteract the change and return the system condition to its proper level. In general, these control devices act as electric switches to turn the proper system component on or off, according to the change of the condition. Typical of these operating controls are the thermostat, humidistat, and pressurestat.

Actuating or secondary controls indirectly control the operation which is carrying out the corrective measure. Among this group of controls are the **relays** (or contactors), **solenoid valves**, water valves, four-way reversing valves, and **back pressure regulators**.

Limiting and safety controllers provide shut-off mechanisms which limit temperatures and pressures within a system before any harm occurs. These controllers will take over the control of the actuators, regardless of what the operating controls are doing. They are connected in series with the operating controls so that an abnormal condition at any one of the controls will stop the operation of the system. Controls in this classification are safety thermostats, high pressure and low pressure cut-offs, thermal and electrical overloads, and **fusible plugs**.

New terms and words

Armature – a part of an electric motor, generator, or other device moved by the application of a magnetic field.

Back pressure regulator (or evaporator pressure regulator) – a regulating valve found in the suction line of an evaporator which maintains the low side pressure above a desired setpoint.

Fusible plug – a fitting made with a metal of a known low melting temperature and used as a safety device to release pressure in case of extreme heat.

Potential – electrical force which moves electrons along a conductor or resistance, producing a magnetic field.

Relay – an electromagnetic mechanism moved by a small electrical current in a control circuit. It opens or closes a valve or switch in an operating circuit.

Solenoid valve – an electromagnet with a moving core which opens or closes a valve in a refrigerant filled line.

Equipment required

- Refrigeration System Trainer, Model 3401

Exercise 5-1

Pressure Controllers

Exercise Objective When you have completed this exercise, you will be able to explain the operation of pressure controllers by observing one in a system.

Discussion Outline The Discussion of this exercise covers the following points:

- Introduction

Discussion

Introduction

A low pressure must be maintained in the evaporator in order for refrigerant to evaporate. Automatic control of the compressor can therefore be based on a design pressure in the evaporator. The type of control used for this is a bellows/diaphragm operated low pressure controller, as shown in Figure 5-1.

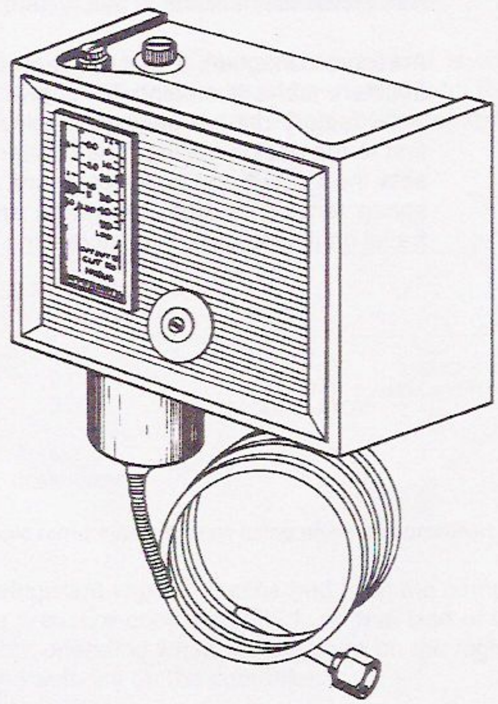


Figure 5-1. Low pressure controller.

The low pressure controller is connected to the low side or suction side by means of a capillary tube. When the evaporator pressure rises, the low side pressure increases above the setting of the controller. This causes an increase in pressure on the bellows of the pressure control. The bellows expands and activates a

switch to start the compressor. The compressor will run until the evaporator pressure is brought down to the preset pressure setting of the controller.

A drop in pressure correspondingly reduces the pressure on the bellows. The bellows then contracts, opening contacts to automatically shut off the compressor.

The high pressure controller operates in a similar manner to the low pressure controller but on the high side of the system. The contacts open on a rise above the setpoint. High and low pressure controls can be used together in a single refrigeration system.

Low pressure controllers are used as both a safety control against pulling a vacuum, causing damage to the compressor, and as a temperature control.

Since changes in evaporator temperature correspond to changes in suction pressure, the low pressure controller can indirectly be used to control refrigerated space temperatures. A thermostat can therefore be eliminated as the compressor will cut out and cut in at the set temperature and pressure. The low pressure controller can also be set to prevent ice formation on the evaporator.

High pressure controllers are used mainly as a safety control. This control cycles the compressor off in the event of excessively high pressure in the system. The high pressures are caused by elevated ambient condensing temperature, and non-condensable fluids in the system, such as water.

Pressure controllers usually have two main adjustments: a range adjustment and a differential adjustment, as shown in Figure 5-2. However, some controllers have factory pre-set settings. The range adjustment screw should be adjusted first to the design setting. The differential adjustment screw can then be set. This sets the cut-out and cut-in pressure allowance above and below the setpoint. A spring tension on both the range and differential screws causes more or less travel on the bellows, thus increasing or decreasing the pressure on the bellows.

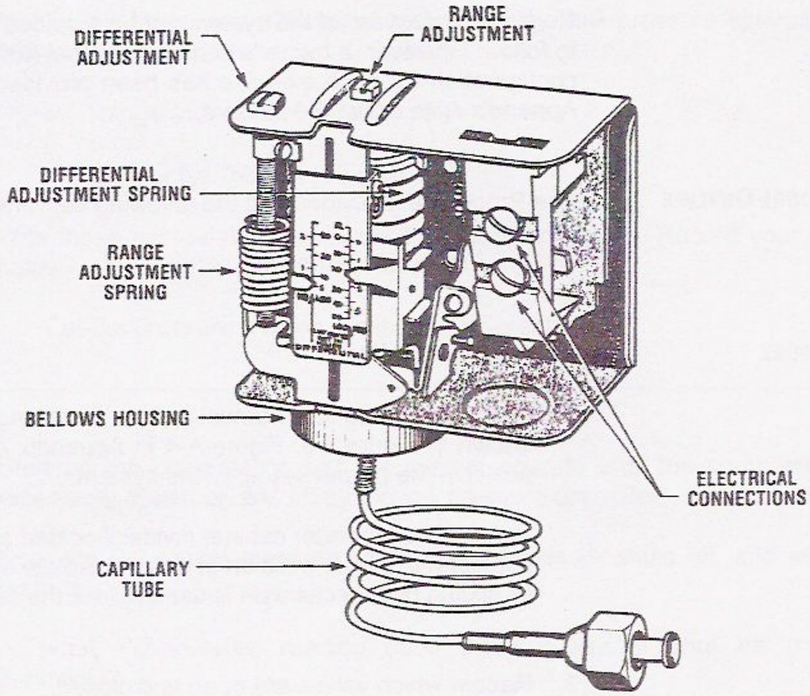


Figure 5-2. Pressure controller settings.

A schematic diagram of a simple refrigeration system is shown in Figure 5-3. This diagram indicates which devices must be used to form the system. Pressure sensing points are also shown to indicate where measurements should be taken.

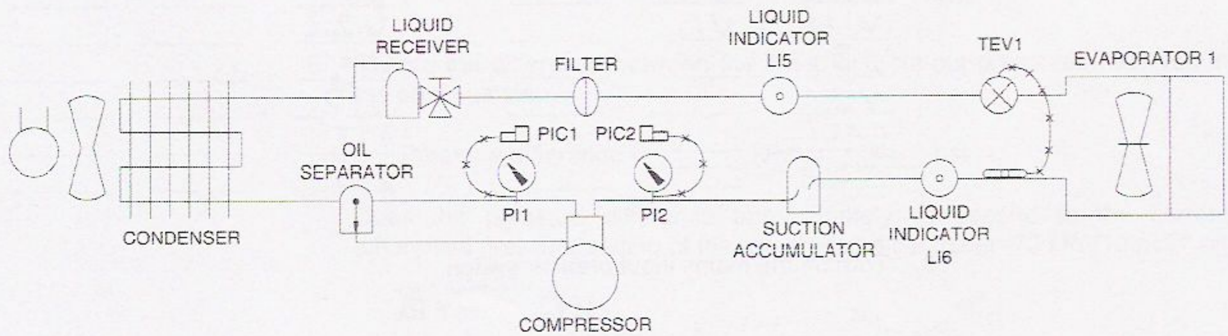


Figure 5-3. Simple refrigeration system using pressure controllers (PIC1 and PIC2).

A high pressure refrigerant vapor is discharged from the compressor and into the condenser. A high pressure controller, PIC1, on this side of the system will stop the compressor from operating when the pressure on the high side of the system increases above the setpoint on the controller.

High pressure liquid refrigerant flows from the condenser and through the liquid receiver, providing a constant supply of liquid refrigerant to the expansion valve. Low pressure refrigerant flows from the expansion valve and through the evaporator to the suction side of the compressor. A low pressure controller, PIC2, on this side of the system will stop the compressor when the suction pressure falls below the setpoint on the controller.

No pictorial diagram of the system will be provided in this exercise or in exercises to follow. However, a trainer's schematic panel (tubing section) showing the valve configuration for each exercise has been provided at the back of the manual in Appendix A, to assist the student.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Pressure controllers

PROCEDURE

Pressure controllers

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 5-3. Figure A-4 in Appendix A may be used at this point to assist in the proper set-up of the system.

   Place the evaporator cabinet divider (located at the top of the two evaporator cabinets) in the up position in order to isolate evaporator 1 from evaporator 2. (A sliding bolt mechanism is used to lock the cabinet divider into place).

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
V16	V12		V9	V6	
V5	V11		V7	V4	
V24	V8		V10		
V14	V1		V22		
V3			V13		
V2			V15		
V21			V17		
V23			V18		

3. Turn on the mains input breaker switch.

4. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to maximum.

5. Observe and record the low-side pressure controller range and differential settings (factory settings).

   Range (cut-in) setting: _______ kPa or ~~35~~ ~~36~~ 35 psi

   Differential setting: _______ kPa or 12 psi

cut-in = 35

cutout = 23

6. Modify the range and differential settings of the low pressure controller as follows:

   - Range (cut-in): 210 kPa (30 psi)
   - Differential: 70 kPa (10 psi)

   With these new settings, calculate the cut-out pressure. Record your result below.

   Cut-out pressure = cut-in pressure – differential

   ____

7. Start up the compressor. Let the system operate until the compressor is repeatedly cycled on and off by the low pressure controller.

   Note the PI2 gauge pressure when the compressor shuts off, and when it restarts.

   At what PI2 pressure reading does the compressor shut off (cut-out pressure)?

   Cut-out pressure = ______ kPa or __23__ psi

   At what PI2 pressure reading does the compressor restart (cut-in pressure)?

   Cut-in pressure = ______ kPa or __35__ psi

8. Record the difference between the cut-in and cut-out pressures recorded in the previous step.

   Pressure difference = ______ kPa or __12__ psi

   Does the pressure difference approximately correspond to the current differential pressure setting of the low pressure controller (70 kPa/10 psi)?

   ☒ Yes ☐ No

9. Return the low-side pressure controller range and differential settings to the initial values recorded in procedure step 5.

10. Observe and record the high-side pressure controller range and differential settings (factory settings):

    Range (cut-out) setting: ______ kPa or ______ psi

    Differential setting: ______ kPa or ______ psi

11. Decrease the high-side pressure controller range (cut-out) setting to 1400 kPa (200 psi) by screwing the range-setting screw clockwise.

    Then, slowly close valve V2 partially, while observing the PI1 gauge pressure reading, until the compressor shuts off.

    At what PI1 pressure reading does the compressor shut off (cut-out pressure)?

    Cut-out pressure = _______ kPa or _______ psi

    At what PI1 pressure reading does the compressor restart (cut-in pressure)?

    Cut-in pressure = _______ kPa or _______ psi

12. Record the pressure difference between the cut-in and cut-out pressures recorded in the previous step.

    Pressure difference = _______ kPa or _______ psi

    Does the pressure difference approximately correspond to the current differential pressure setting of the high pressure controller (350 kPa/50 psi)?

    ❑ Yes ❑ No

13. Return the high-side pressure controller range setting to the initial value recorded in procedure step 10.

14. Turn off the condenser and evaporator fans.

15. Turn off the compressor and main breaker switch.

CONCLUSION

Pressure controllers are used in refrigeration systems as safety controls and temperature controls. There are two different types of pressure controllers: low pressure controllers and high pressure controllers.

Low pressure controllers are found on the suction side of the system and will maintain the low side pressure of the refrigeration system below the required level to ensure efficient vaporization of liquid refrigerant. At the same time, low pressure controllers prevent the system from drawing a vacuum which may damage the compressor unit.

High pressure controllers are found on the high or discharge side of the system and will maintain the high side pressure to the required level necessary for efficient condensation of the refrigerant vapor within the condenser. At the same time, the pressure controller will prevent the high side pressure from becoming excessively high, which may cause components within the system to rupture.

REVIEW QUESTIONS

1. What are the two types of pressure controllers commonly used on refrigeration systems and where is each found in the system?

The two pressure controllers are the low and high pressure controllers. The low pressure controller is found in the suction line while the high pressure controller is found in the discharge line.

2. What is the purpose of a low pressure controller?

The low pressure controller maintains a preset pressure in the evaporator. When the evaporator pressure increases, the low pressure controller turns on the compressor and makes it run until the evaporator pressure has decreased

3. Describe the operation of a low pressure controller.

The low pressure controller is connected to the suction side of evaporator. When the temperature rises in evaporator, the bellows in the pressure controls expand and closes a switch that turns on the compressor. When pressure in evaporator drops, the bellows contract and the switch is opened, shutting off the compressor

4. What is the purpose of a high pressure controller?

Its purpose is to shut off the compressor in case of excessively high pressure in the system

5. Describe the operation of a high pressure controller.

The high pressure controller is connected between the compressor and condenser. It maintains a desired high-side pressure. If this pressure is exceeded, the bellows in the controller will expand and operate a switch that will turn the compressor off.

Exercise 5-2

Thermostatic Controls

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to explain the operation of a thermostatic controller by using one in a refrigeration system.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Introduction

DISCUSSION

Introduction

Thermostatic controls used in refrigeration systems are frequently called remote bulb thermostats. This type of control operates in a similar manner to the pressure controller.

The thermostat, as shown in Figure 5-4, has a remote bulb or a thermal bulb similar to that of a thermostatic expansion valve. The bulb is usually filled with the same refrigerant used in the system. The refrigerant, as in the system, is sensitive to temperature. A temperature rise at the bulb will expand the refrigerant in the bulb, causing a pressure increase on the bellows. The bellows then expands to activate a switch. The switch will open or close to activate the compressor or a solenoid valve.

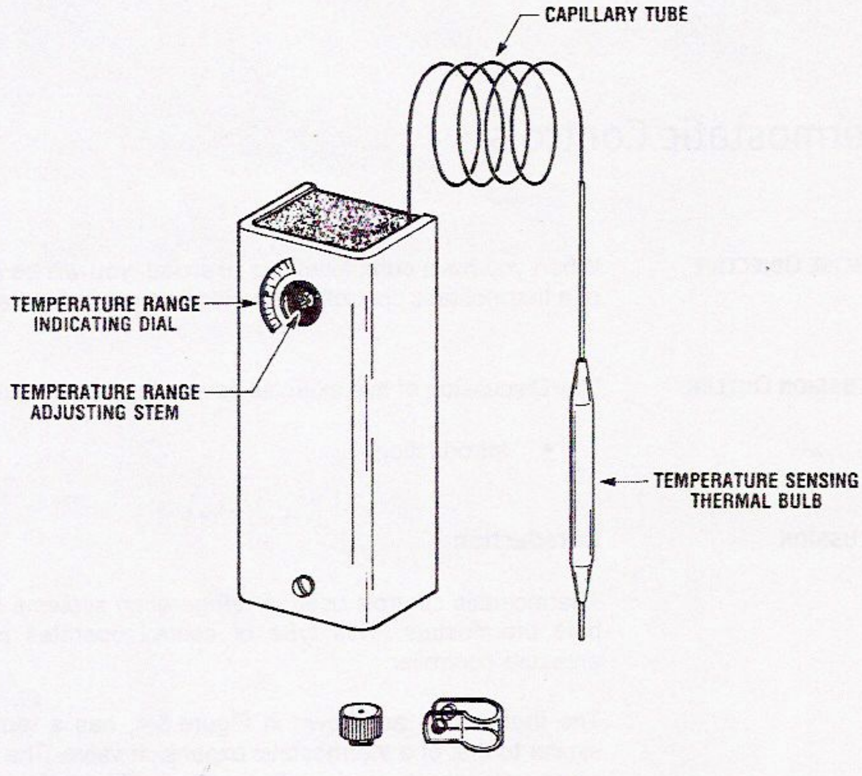


Figure 5-4. Thermostatic controller.

The thermal bulb is usually a capillary tube with an expanded end that is used to store the refrigerant. The bulb is usually mounted on the side of the evaporator, or in a convenient place in the refrigerated space, but not directly in the air stream.

Thermostatic controls are supplied with an adjustable range and differential range, similar to pressure controllers, except for their scales. Preset factory sealed units are also quite common. Range and differential adjustments on a thermostatic controller are shown in Figure 5-5.

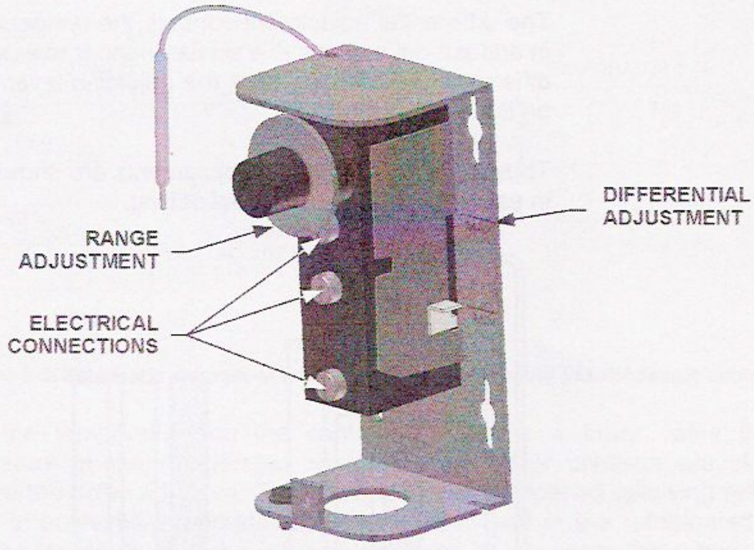


Figure 5-5. Range and differential adjustment.

Thermostatic controls, also known as temperature actuated switches, are used in control circuits to operate heaters, blowers, fans, solenoid valves, pumps and other devices. For example, a thermostatic controller would be used to control the operation of a solenoid valve in a multiple evaporator system. The valve would control on/off refrigerant flow to the evaporators.

The range adjustment provides for the correct minimum and maximum temperature or pressure in an automatically operated system. For example, the range adjustment will keep a refrigerated space between certain temperatures. The range adjustment can be set to the desired temperature and then protected from adjustment by a snap in plug. The plug however can be replaced by a dial. The dial is used if frequent adjustments are to be made. The dial can be set to stop at a certain point by the use of a stop screw, as shown in Figure 5-6.

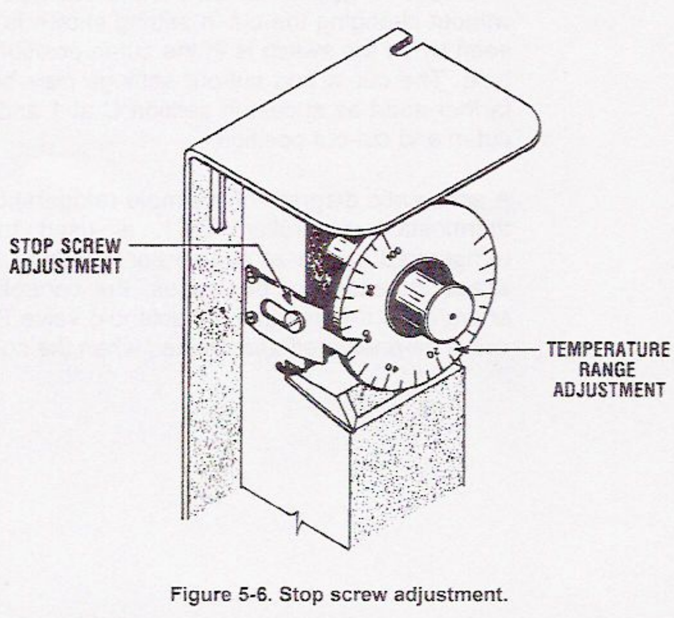


Figure 5-6. Stop screw adjustment.

The differential adjustment controls the temperature difference between the cut-in and cut-out settings in a similar manner to a pressure controller. To change the differential adjustment, slide the adjusting lever to the desired differential setting on the scale plate.

Three types of differential adjustments are shown in Figure 5-7. The shaded area in each illustration is a normal setting.

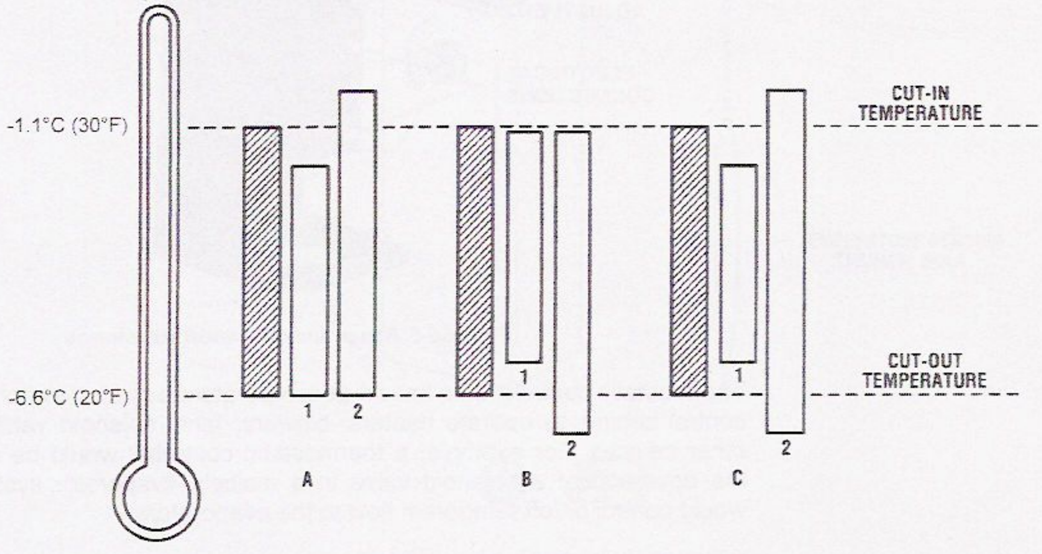


Figure 5-7. Differential adjustments.

The first case is called the cut-in type. The cut-in point may be moved without changing the cut-out shown in section A at 1 and 2. The effect is seen only when the switch is in the cut-out position.

The second type is called the cut-out type. The cut-out point may be moved without changing the cut-in setting shown in section B at 1 and 2. The effect is seen when the switch is in the cut-in position. The third type is called the double type. The cut-in and cut-out settings may be brought closer together or moved farther apart as shown in section C at 1 and 2. This adjustment affects both the cut-in and cut-out position.

A schematic diagram of a simple refrigeration system is shown in Figure 5-8. A thermostatic controller, TIC1, is used to control the temperature of the refrigerated space at evaporator 1. When the temperature of the refrigerated space increases or decreases, the controller opens or closes its contacts to energize or de-energize the solenoid valve SV1. The solenoid is closed when its coil is de-energized and opened when the coil is energized.

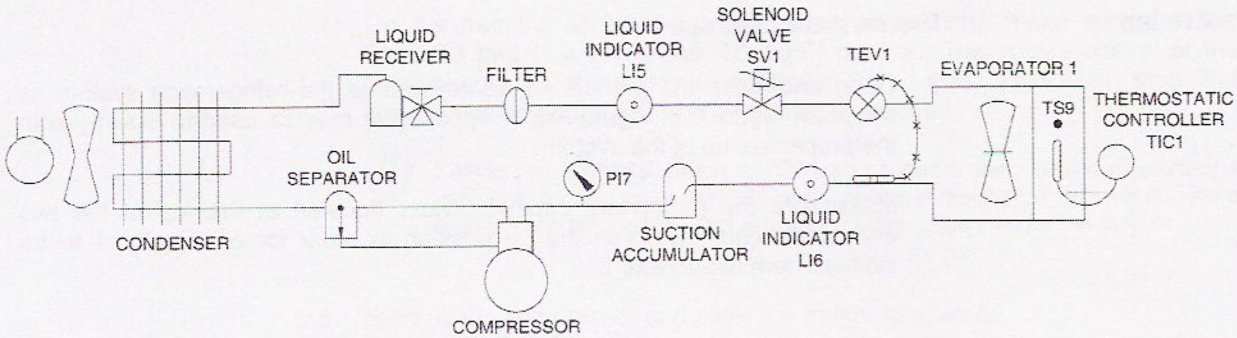


Figure 5-8. Schematic diagram of a refrigeration system using a thermostatic controller.

When the temperature on the controller is set to a lower value than the temperature of the refrigerated space, the controller contacts are closed to energize the solenoid valve. The valve is therefore opened, allowing refrigerant to flow through the evaporator and absorb the heat in the refrigerated space. When the temperature of the refrigerated space decreases to the setpoint on the controller, the controller contacts open to de-energize the solenoid valve coil. The valve therefore closes to stop refrigerant flow to the evaporator. The compressor also shuts off when the cooling compartment temperature has been obtained.

When the temperature in the refrigerated space increases above the setpoint on the thermostatic controller, the controller contacts close to energize the solenoid valve. The valve therefore opens to allow refrigerant to flow to the evaporator and starts the compressor. The temperature in the refrigerated space is then decreased to the thermostatic controller setpoint.

Procedure Outline

The Procedure is divided into the following sections:

- Thermostatic controls

PROCEDURE

Thermostatic controls

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 5-8. Figure A-5 in Appendix A may be used to assist you in the proper set-up of the system.

   Make sure the evaporator cabinet divider (located at the top of the two evaporator cabinets) is in the up position in order for evaporator 1 to be isolated from evaporator 2.

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
V16	V12		V9	V6	
V5	V11		V7	V4	
V24	V8		V10		
V14	V1		V22		
V3			V13		
V2			V15		
V21			V17		
V23			V18		

3. Turn on the mains input breaker switch.

4. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to maximum.

5. Turn on the breaker switch of thermostatic controller 1 (on the trainer's right-hand side control panel).

   Locate this controller (TIC1) on the Refrigeration System Trainer. Remove the cover of this controller by loosening its screw.

   - Adjust the range setting (temperature setpoint) of the controller to 4°C (40°F).
   - Make sure the differential adjustment lever is set to the **"MIN."** position. (Refer to Figure 5-5, if necessary, to see the location of the differential adjustment lever).

6. Place a temperature probe into the evaporator-1 cabinet (temperature sensing point TS9).

7. On the trainer's schematic panel (electrical section), make sure that the BYPASS switch is set to the "O" (OFF) position. This allows control of the compressor by thermostatic controller TIC1; thus TIC1 will stop the compressor when the TIC1 range setting is reached.

   Setting the BYPASS switch to "O" also causes a lamp in the evaporator-1 cabinet to turn on when the TIC1 range setting is reached, in order to provide a heat load on the system. This provides a faster cycle time for the system.

8. Start up the compressor and allow the trainer to operate.

   Meanwhile, observe the decreasing temperature in the evaporator-1 cabinet on the thermometer.

   - As long as this temperature is above the range (cut-out) setting of thermostatic controller TIC1, solenoid valve SV1 stays energized (open), allowing refrigerant to flow through evaporator 1.

   - Therefore, on the trainer's right-hand side control panel, the lamp "OPEN" of solenoid valve SV1 is lit, while the lamp "CLOSED" of this solenoid is closed.

   Wait until the lamp "OPEN" of solenoid valve SV1 turns off and the lamp "CLOSED" of this solenoid turns on. At that precise moment, note the thermometer reading and record it below. (Since the compressor will then start to cycle on and off, make sure to take your reading when the lamp "CLOSED" turns on).

   Evaporator-1 cabinet temperature
   [SV1 de-energized (closed)]: ______ °C or 41 °F

   Does the recorded temperature approximately correspond to the range setting of thermostatic controller TIC1? Explain.

   Yes. The cut-out was set to 40°F give or take a few degrees and that is when the solenoid "closed" light turned on.

9. Observe the operation of the system as it is cycled on and off. When solenoid valve SV1 is de-energized (closed), the suction line pressure at gauge PI2 drops rapidly to the cut-out pressure setting of the low pressure controller (PIC2), which shuts off the compressor. The temperature in the evaporator-1 cabinet starts to re-increase, along with the suction line pressure.

When the increasing temperature in the evaporator-1 cabinet has increased by a certain amount (equal to the range setting of thermostatic controller TIC1 plus the TIC1 minimum differential of about 3°C/5.4°F), solenoid valve SV1 is energized (opened), causing the lamp "OPEN" of this solenoid to turn on, and the "CLOSED" lamp of this solenoid to turn off. At that precise moment, note the thermometer reading and record it below.

Evaporator-1 cabinet temperature
[SV1 re-energized (opened)]: ______ °C or 48.2 °F

10. On thermostatic controller TIC1, increase the differential from minimum to medium. To do so, set the differential adjustment lever **halfway** between the "**MIN.**" and "**MAX.**" position (refer to Figure 5-5, if necessary, to see the location of the differential adjustment lever).

11. Observe the operation of the system as it is cycled on and off.

Note and record the thermometer reading when the lamp "OPEN" of solenoid valve SV1 turns off and the lamp "CLOSED" of this solenoid turns on. (At that moment, solenoid valve SV1 is de-energized, stopping the refrigerant flow to evaporator 1).

Evaporator-1 cabinet temperature
[SV1 de-energized (closed)]: ______ °C or ______ °F

Then, note and record the thermometer reading when the lamp "CLOSED" of solenoid valve SV1 turns on and the lamp "OPEN" of this solenoid turns off. (At that moment, solenoid valve SV1 is re-energized, allowing refrigerant to flow to evaporator 1.)

Evaporator-1 cabinet temperature
[SV1 re-energized (opened)]: ______ °C or ______ °F

12. Compare the temperatures recorded in step 11 for a medium temperature differential to those recorded in steps 8 and 9 for a lower temperature differential.

Were the temperatures read when valve SV1 was de-energized the same for both differentials? Explain.

____

____

Were the temperatures read when valve SV1 was re-energized the same for both differentials? Explain.

____

____

13. On thermostatic controller TIC1, set the differential adjustment lever back to the **"MIN."** position.

    Set the cover of the thermostatic controller back into place by tightening its screw.

14. Turn off the evaporator and evaporator fans.

15. Turn off the compressor and main breaker switch.

CONCLUSION

Thermostatic controls operate in a similar manner to pressure controls. This type of control uses a sensing element to detect a change in temperature in the system. Range and differential adjustments provide control for the thermostatic controller. Thermostatic controllers are used in control circuits which operate heaters, blowers and solenoid valves.

REVIEW QUESTIONS

1. What is another name for a thermostatic controller?

   It's a temperature-activated switch

2. What is a remote bulb?

   A thermal bulb is a device connected to the thermostatic controller that contains refrigerant

3. How does a thermostatic controller operate?

   It operates by using the refrigerant, connected to the evaporator, to sense a change in temperature. When the temperature increases, the refrigerant will expand and push down on the bellows/diaphragm, thereby activating a switch

4. What types of devices are controlled by thermostatic controllers?

   Heaters, blowers, fans, pumps, solenoids, among others.

5. What does "cut-in" refer to when adjusting the differential setting on a thermostatic controller?

Cut-in is the temperature ~~at~~ which the pressure controller will flip a switch to activate a component

Exercise 5-3

Solenoid Valve Controls

EXERCISE OBJECTIVE When you have completed this exercise, you will be able to explain the operation of solenoid valve controls as used in a refrigeration system.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Applications

DISCUSSION In previous exercises, single evaporator control was discussed. However, in multi-evaporator systems, the method of control used is different. For example, in a two evaporator system, one evaporator may be required to operate when the other evaporator is not, without shutting off the compressor.

To do this, thermostatic controllers and solenoid valves are used to control the evaporators separately. The thermostatic controller contacts are connected in parallel for controlling the compressor. The compressor will shut off only if both controllers are satisfied. The thermostatic controllers each control the operation of a solenoid valve such as the one shown in Figure 5-9.

Figure 5-9. Solenoid valve.

When a temperature setting on either evaporator is reached, the controller contacts open or close to energize or de-energize the solenoid valves. The solenoid valves control the flow of refrigerant to each evaporator without affecting the operation of the other evaporator.

A solenoid valve is simply an electromagnet with a movable core or center. The basic construction of a solenoid valve includes a movable **armature** which is attached to a valve needle. This assembly is sealed inside the valve body so that the armature can raise or lower the valve needle. A coil is wound around the valve housing which contains the armature. The basic construction of a solenoid valve is shown in Figure 5-10.

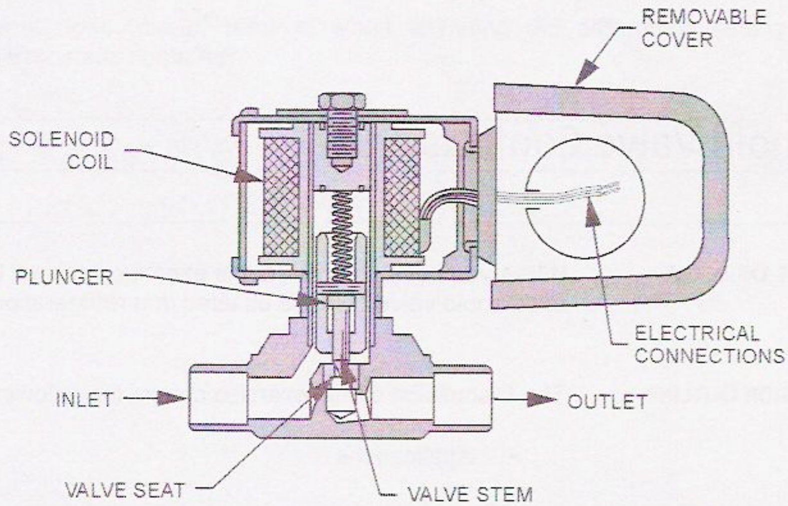


Figure 5-10. Cross-sectional view of a solenoid valve.

When the coil is energized, the armature is attracted toward the center of the coil, which opens the valve. When the coil is de-energized, the spring and weight of the armature force the valve against the valve seat, preventing refrigerant from flowing to the evaporator. This common type of solenoid valve is known as a normally closed solenoid valve. The valve is always fully closed when de-energized or fully open when energized. A minimum pressure drop is usually required across the valve to hold the valve in the open position.

Applications

Solenoid valves are used in refrigeration systems to control the flow of refrigerant liquid to the evaporator. The solenoid valve is installed in the liquid line before the metering device. The intended purpose is to prevent the flow of liquid refrigerant to the evaporator when the compressor is cycled off; provide individual temperature control in each room of a multiple system; and control the number of evaporator sections used, as the load varies, on large refrigeration systems. A thermostatic controller is usually used to operate the solenoid valves in these types of applications.

A schematic diagram of a multiple evaporator system using solenoid valve control is shown in Figure 5-11. The evaporators are controlled separately by solenoid valves and thermostatic controllers. Two TEV's are used to provide different pressures within the evaporators. The thermostatic controllers can be set to a specific temperature to stop refrigerant flow to the evaporators through the solenoid valves when the desired space temperature is reached. The thermostatic controller de-energizes the solenoid valve, stopping liquid refrigerant from flowing into the evaporator.

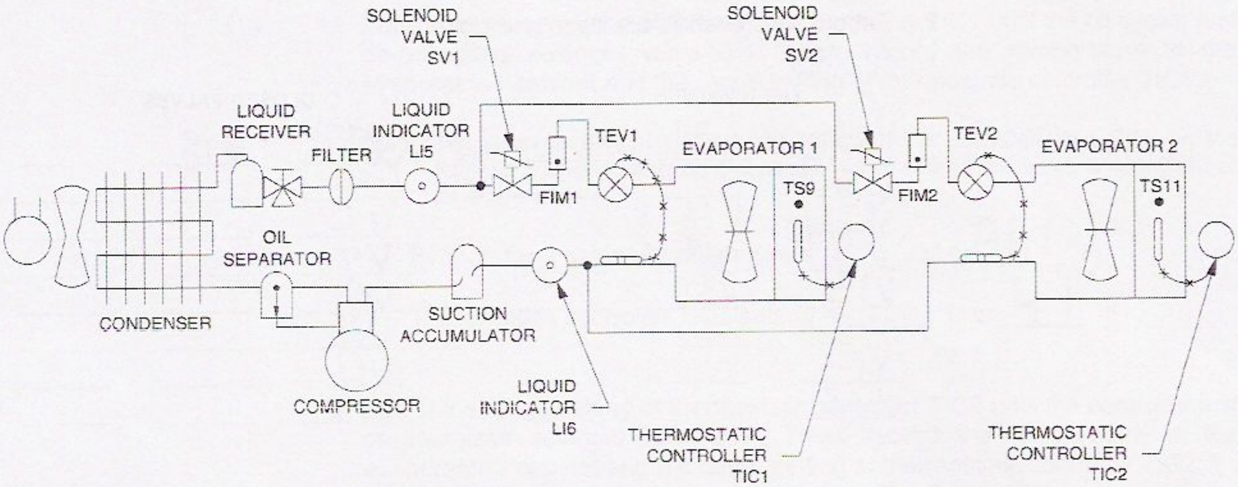


Figure 5-11. Schematic diagram of a multi-evaporator refrigeration system using solenoid valve control.

When the temperature of the refrigerated space rises above the setpoint, the thermostatic controller energizes the solenoid valve which opens to allow refrigerant to flow to the evaporator. The temperature of the refrigerated space will then decrease below the setpoint on the thermostatic controller.

When the desired condition in both refrigerated spaces is met (reached setpoint), the thermostatic controllers activate to close the solenoid valves and stop the compressor. If the condition in a refrigerated space goes outside the desired range and the temperature rises above the setpoint, the corresponding thermostatic controller energizes its solenoid valve to restart the compressor.

On the system trainer, lamps will be illuminated in the refrigerated space when the condition in the space is satisfied. This provides a heat load to the space which decreases the cycle time.

Procedure Outline

The Procedure is divided into the following sections:

- Solenoid valve controls

Procedure

Solenoid valve controls

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 5-11. Figure A-6 in Appendix A may be used at this point to assist in the proper set-up of the system.

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
V16	V21		V7	V18	
V5	V1		V10		
V24	V11		V22		
V3	V9		V4		
V13	V8		V6		
V2			V15		
V12			V14		
V23			V17		

3. Turn on the mains input breaker switch.

4. Set the speed of the condenser fan, evaporator-1 fan, and evaporator-2 fan to medium.

5. Place the temperature probes of the temperature meter into the cabinets of evaporators 1 and 2, through the orifice on top of these cabinets.

6. Place the evaporator cabinet divider (located at the top of the two evaporator cabinets) in the up position in order to isolate evaporator 1 from evaporator 2. (A sliding bolt mechanism is used to lock the cabinet divider into place).

7. Make sure the BYPASS switch on the electrical section of the trainer's schematic panel is set to "O" (OFF).

8. Adjust the thermostatic controllers for a low temperature setting (around −7°C/20°F) to ensure an appropriate stabilizing time for the system. This will ensure that the controllers do not shut off the compressor before normal operating conditions are established upon initial start-up.

9. Turn on the breaker switches of thermostatic controllers TIC1 and TIC2.

10. Start up the compressor and operate the trainer for approximately 10 minutes. This allows the system to stabilize before any readings are taken.

11. Adjust the range setting of thermostatic controller TIC1 until the controller just de-energizes solenoid valve SV1. Then, record the temperature in the evaporator-1 cabinet and the range setting of thermostatic controller TIC1.

The indicator lamps "OPEN" and "CLOSED" of solenoid valve SV1 (on the trainer's right-hand side control panel) indicate when this valve is energized or de-energized.

Evaporator-1 cabinet temperature = ______ °C or 51.1 °F

Thermostatic controller TIC1 setting = ______ °C or 41 °F

12. Adjust the range setting of thermostatic controller TIC2 until the controller just de-energizes solenoid valve SV2. Then, record the temperature in the evaporator-2 cabinet and the range setting of thermostatic controller TIC2.

The indicator lamps "OPEN" and "CLOSED" of solenoid valve SV2 (on the trainer's right-hand side control panel) indicate when this valve is energized or de-energized.

Evaporator-2 cabinet temperature = ______ °C or 44.5 °F

Thermostatic controller TIC2 setting = ______ °C or 50 °F

13. Allow the thermostatic controllers to cycle the system several times. The indicator lamps of solenoid valves SV1 and SV2 will help follow the operation of the thermostatic controllers and solenoid valves.

14. Observe flow indicating meter FIM1. Describe your observations as the system cycles and explain by referring to the opening and closing of solenoid valve SV1.

~~Liquid~~ First there was nothing in the flow meter but as SV1 opened up it started to bubble, indicating saturated refrigerant

15. Observe flow indicating meter FIM2. Describe your observations as the system cycles and explain by referring to the opening and closing of solenoid valve SV2.

As SV2 was closed, FIM2 was bubbly/clear, but as soon as FIM2 opened it became progressively more clear

Does the operation of thermostatic controller TIC1 and solenoid valve SV1 affect the operation of evaporator 2? Explain.

Yes, if one soleroid valve is closed the refrigerant

16. Adjust both thermostatic controllers to the maximum (highest) temperature setting. What happens to the solenoid valves? To the compressor? Why?

The solenoid valves both close due to the high cut-in temperature. The compressor shuts off due to it being controlled by the thermostatic controllers

17. Turn off the compressor breaker switch.

18. Turn off the evaporator and condenser fans.

19. Turn off the breaker main switch.

CONCLUSION

In refrigeration system using dual evaporators in parallel, it is necessary to provide a means of controlling the flow of refrigerant to each evaporator. It must also be possible to stop the flow of refrigerant to one evaporator without affecting the flow of refrigerant to the other evaporator or affecting the operation of the compressor. Solenoid valves controlled by thermostatic controllers provide this operation.

When the temperature condition is satisfied in the cooling compartment of one evaporator, the thermostat will energize a solenoid valve and stop the flow of refrigerant to that evaporator without affecting the compressor. When both evaporator temperature conditions are satisfied, both solenoid valves close and the compressor shuts off.

REVIEW QUESTIONS

1. When are solenoid valves used in a refrigeration system?

They're used for seperate evaporator control. as

2. Describe the operation of a normally closed solenoid valve.

In a n.c solenoid valve a solenoid valve coil becomes energized, which will attract the solenoid armature towards it and away from the valve opening. When the solenoid is de-energized the armature's spring and weight causes ~~the~~ armature to close the valve seat

3. What are three possible applications for solenoid valves in refrigeration systems?

Three possible applications are for multiple evaporator systems, preventi refrigerant flow to the evaporator, and controlling each evaporator section

4. Where are solenoid valves usually located in a typical refrigeration system?

They are located in the liquid line, after the filter and before the TEV

5. When will the compressor shut off in a multiple evaporator refrigeration system, with thermostatic and solenoid valve control?

The compressor will shut off when the temperature conditions in ALL the refrigerated spaces have been met

Back Pressure Regulator

EXERCISE OBJECTIVE When you have completed this exercise, you will be able to explain the function and operation of a back pressure regulator valve.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Operation
- Application

DISCUSSION

The back pressure regulator, as shown in Figure 5-12, is also called an evaporator back pressure regulator. The regulator prevents the evaporator pressure from falling below a predetermined pressure setting. This pressure setting can also be adjusted to prevent the evaporator from freezing. The regulator is used in the evaporator outlet or suction line where low limit control of the evaporator pressure or temperature is required.

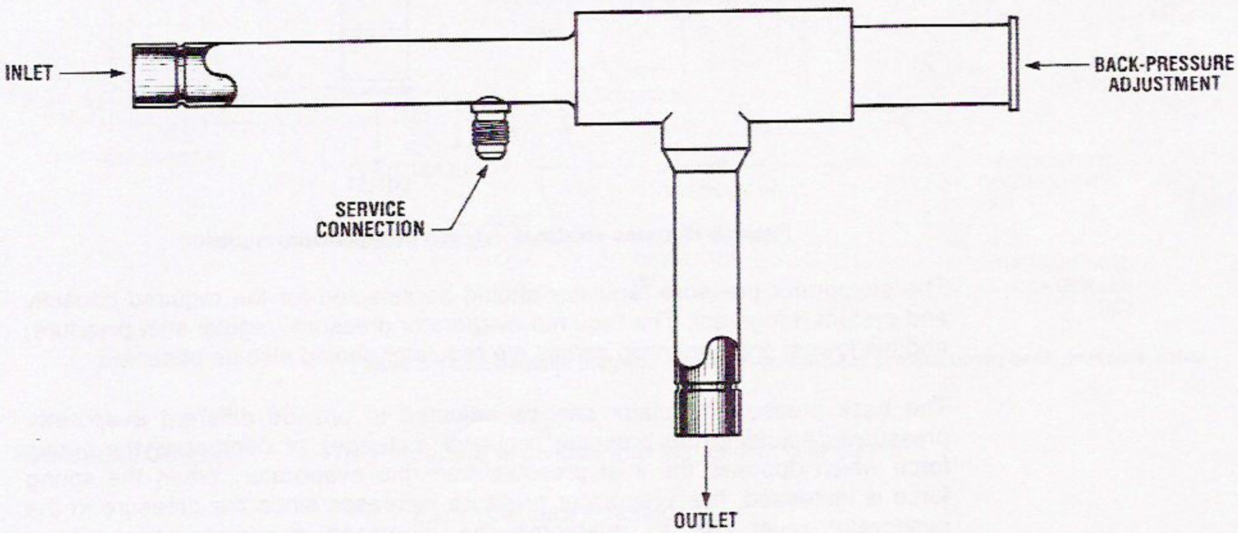


Figure 5-12. Back pressure regulator.

Operation

A cross-sectional view of a back pressure regulator with the major components identified is shown in Figure 5-13. The inlet pressure acts on the bottom of the seat disc which is opposed by an adjusting spring. When the evaporator pressure exceeds the force exerted by the spring, the valve moves in an opening direction. When the evaporator pressure falls below the force exerted by the spring, the valve moves in a closing direction. Therefore, the back pressure regulator assumes a throttling position to balance the system load.

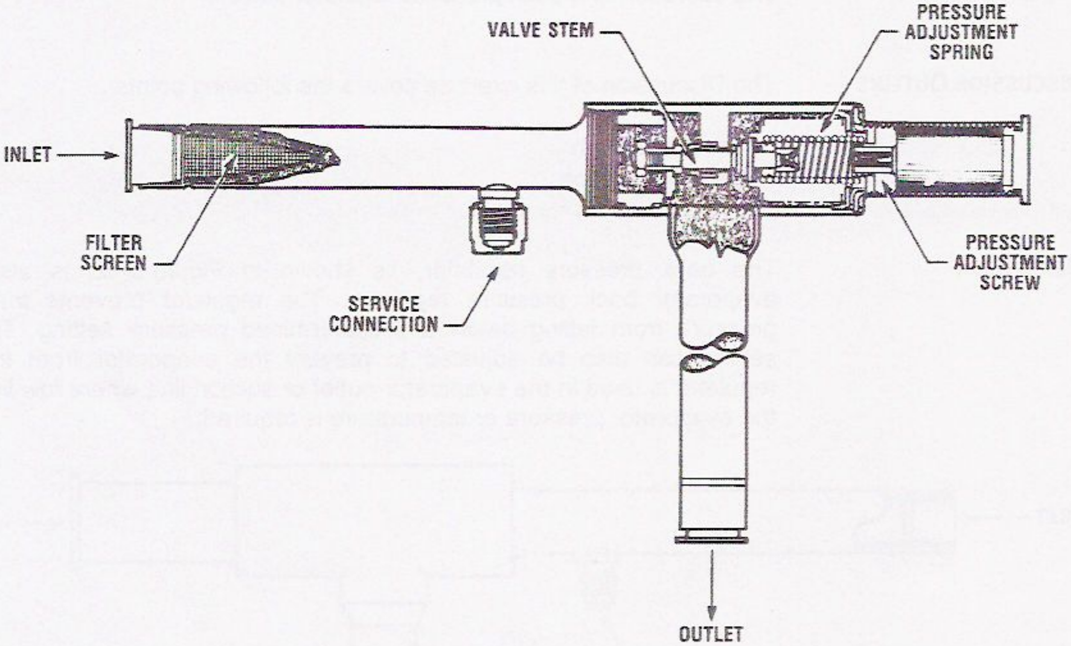


Figure 5-13. Cross-sectional view of a back pressure regulator.

The evaporator pressure regulator should be selected for the required capacity and system refrigerant. The required evaporator pressure (regular inlet pressure) and the lowest pressure drop across the regulator should also be observed.

The back pressure regulator can be adjusted to provide different evaporator pressures. Adjusting the pressure regulator increases or decreases the spring force which opposes the inlet pressure from the evaporator. When the spring force is increased, the evaporator pressure increases since the pressure in the evaporator must rise to overcome the increased opposing spring force. Conversely, if the spring force is decreased, the evaporator pressure decreases.

Application

Back pressure regulators are used on fined coil evaporators where "frosting back" of the evaporator is undesirable. They are also used when the evaporator pressure must be maintained constant and higher than suction pressure in order to prevent dehumidification.

The regulator is used on single evaporator units, such as a water cooler or multiple evaporator systems, to maintain certain minimum pressures on individual evaporators.

On a multi-evaporator system, the regulators prevent lowering of the desired evaporator temperature in the warmer units, while the compressor continues to operate the coldest unit. This is common in supermarkets where, in the same freezer, one section is used as a freezer and another section as a cooler. The back pressure regulator also reduces the start-up torque on the compressor.

A schematic diagram of a multiple evaporator system using back pressure regulator control is shown in Figure 5-14. The regulator maintains the pressure in evaporator 1 to a constant desired setting. The pressure in evaporator 2 will be typical of that using a TEV. Therefore, the space temperatures provided by the evaporators will be different.

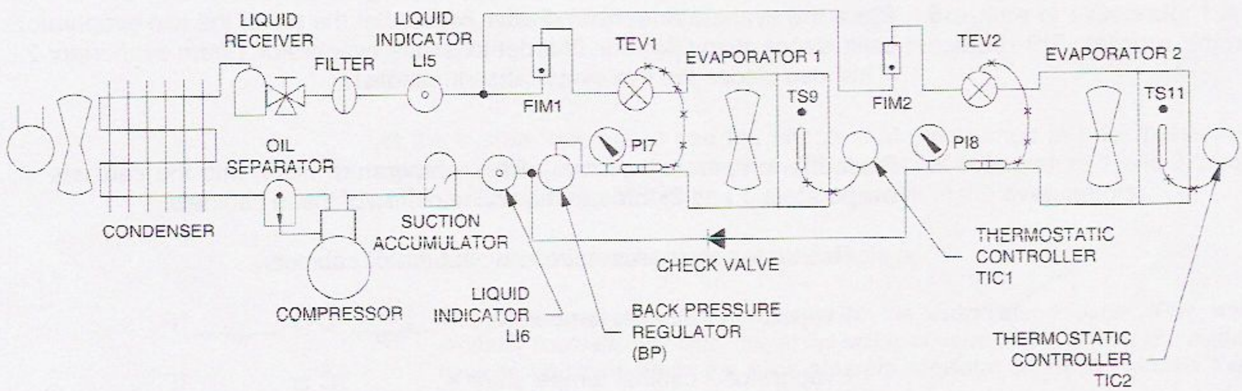


Figure 5-14. Schematic diagram of a multi-evaporator system using back pressure valve.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Back pressure regulator

PROCEDURE

Back pressure regulator

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 5-14. Figure A-7 in Appendix A may be used at this point to assist in the proper set-up of the system.

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
V16	V21		V7	V18	
V5	V1		V10		
V24	V11		V22		
V3	V9		V14		
V13	V8		V6		
V2			V15		
V12			V4		
V23			V17		

3. Turn on the mains input breaker switch.

4. Set the condenser fan speed to maximum. Set the speed of the evaporator-1 fan and evaporator-2 fan to minimum.

5. Place the evaporator cabinet divider (located at the top of the two evaporator cabinets) in the up position in order to isolate evaporator 1 from evaporator 2. (This also places the two evaporators in parallel).

6. Place the temperature probes of the temperature meter into the cabinets of evaporators 1 and 2, through the orifice on top of these cabinets.

   Record the temperature in both evaporator cabinets.

   Evaporator-1 cabinet temperature = ______ °C or ______ °F

   Evaporator-2 cabinet temperature = ______ °C or ______ °F

7. Using a hexagonal wrench, adjust the pressure level screw on the back pressure regulator to its maximum counterclockwise position (about 5 full turns counterclockwise). This will place the minimum back pressure on evaporator 1.

8. Place the BYPASS switch on the electrical schematic panel to the "O" (OFF) position.

9. Turn on the breaker switches of thermostatic controllers TIC1 and TIC2 and adjust the range settings on these controllers to several degrees below the freezing point of water (to around −7°C/20°F).

10. Start up the compressor and operate the trainer for approximately 10 minutes. This allows the system to stabilize before any readings are taken.

11. Allow the system to operate until both evaporators begin to frost over. Record the temperatures in each evaporator cabinet and the outlet pressure of each evaporator.

The settings on the pressure controllers may have to be adjusted if the pressure controllers cut out the compressor before the thermostatic controllers can cycle the system.

Evaporator 1: Cabinet temperature = ______ °C or ______ °F

Outlet pressure (PI7) = ______ kPa or ______ psi

Evaporator 2: Cabinet temperature = ______ °C or ______ °F

Outlet pressure (PI8) = ______ kPa or ______ psi

12. On the back pressure regulator, turn the pressure level adjustment screw clockwise, one full turn at a time, until the outlet pressure of evaporator 1 is approximately 140 kPa (20 psi) above the recorded PI7 pressure from procedure step 11.

Let the system operate to see the effects that the change in back pressure regulator setting has on the condition (frost over) of evaporators 1 and 2, and on the cabinet temperatures and outlet pressures of the evaporators.

Record all your observations below, and explain.

The back pressure initially adjusted at the evaporator-1 outlet (PI7) will probably fluctuate over time, due to the action of valve TEV1, so that you might have to slightly readjust the back pressure regulator screw to maintain the back pressure around the desired value.

____

____

____

____

____

13. Once the system has operated for at least 10 minutes, record the temperature in each evaporator cabinet and the outlet pressure of each evaporator.

While waiting, you will probably have to readjust the back pressure regulator setting to maintain the evaporator-1 outlet pressure at PI7 about 140 kPa (20 psi) above the pressure recorded in step 11.

Evaporator 1:	Cabinet temperature	=	______ °C or ______ °F
	Outlet pressure (PI7)	=	______ kPa or ______ psi
Evaporator 2:	Cabinet temperature	=	______ °C or ______ °F
	Outlet pressure (PI8)	=	______ kPa or ______ psi

14. Compare the evaporator temperatures and pressures recorded in step 13 to those recorded in step 11. Record your observations below.

____

____

____

____

____

____

You should observe that the increase in back pressure regulator setting, which caused the cabinet temperature and outlet pressure of evaporator 1 to increase noticeably, caused little effect on the operation of evaporator 2, whose cabinet temperature and outlet pressure changed much less than those of evaporator 1.

This occurred because, after the increase in back pressure regulator setting, a pressure differential was still maintained by this device between evaporators 1 and 2, allowing a temperature differential to be maintained between the two cabinets.

15. Turn off the evaporator and condenser fans.

16. Turn off the compressor, main breaker and thermostatic controller switches.

CONCLUSION

The evaporator back pressure valve, located in the suction line of refrigeration systems, maintains the evaporator pressure above a preset pressure level.

The regulator valve is used in a single evaporator refrigeration system where the cooling compartment must be maintained at a temperature above the freezing point. The valve is also used in multiple evaporator systems where the second

compartment is maintained at a temperature below the temperature of the first compartment.

The back pressure valve has a pressure adjustment to set the desired pressure level within the evaporator. If the pressure in the evaporator increases above the set level, the spring force opposing the evaporator pressure will be over-taken and the valve will open. When the pressure decreases to the set point the valve will close.

REVIEW QUESTIONS

1. What is a back pressure regulator?

A valve that prevents the evaporator's pressure from falling below a set pressure

2. Where would a back pressure regulator be used?

On systems where coil freezing is unwanted, as well as where evaporator pressure must be constant (and higher than suction pressure)

3. Why would a back pressure regulator be used in a multi-evaporator system?

It would be used to prevent a lower temperature on warmer units as well as to operate the other units at a colder temperature.

4. Describe the operation of a back pressure regulator.

It's a valve that ~~[illegible]~~ when there is a sufficient refrigerant pressure, will open (due to the pressure exerted on the spring). The spring will cause the valve to close when there's a drop in pressure below the set point of the back-pressure regulator.

5. How is a back pressure regulator adjusted for minimal back pressure on the evaporator?

It's adjusted using the pressure adjustment screw

Unit Test

1. Thermostatic or pressure controllers are classified as

   a. operating or primary controls.
   b. actuating or secondary controls.
   c. limiting and safety controls.
   d. None of the above is correct.

2. Solenoid valves or back pressure regulators are classified as

   a. operating or primary controls.
   b. actuating or secondary controls.
   c. limiting and safety controls.
   d. None of the above is correct.

3. A low pressure controller maintains the pressure in the

   a. condenser.
   b. metering device.
   c. system.
   d. evaporator.

4. A high pressure controller is mainly used as a

   a. temperature control.
   b. metering device.
   c. safety control.
   d. flow control.

5. When the condenser pressure rises beyond the set point on the controller, the bellows of the controller

   a. contracts to shut off the compressor.
   b. expands to start the compressor.
   c. expands to shut off the compressor.
   d. contracts to start the compressor.

6. Thermostatic controllers have adjustments for

   a. range setting.
   b. differential setting.
   c. factory pre-set setting.
   d. All the above are correct.

Turn in lab book
Test – OL socrative student

7. Thermostatic controllers are used in refrigeration systems to control the operation of

   a. back pressure regulators.
   b. line tap valves.
   c. solenoid valves.
   d. check valves.

8. The configuration of a normally closed solenoid valve is always

   a. closed when energized.
   b. open when energized.
   c. the valve must be energized to be open or closed.
   d. None of the above is correct.

9. Solenoid valves are used in a multiple evaporator refrigeration system to control the flow of refrigerant to

   a. the condenser.
   b. bypass the compressor.
   c. the cooling compartment.
   d. each evaporator.

10. Back pressure regulators are located in a refrigeration system between the

    a. metering device and the evaporator.
    b. evaporator and the compressor.
    c. compressor and the condenser.
    d. condenser and the metering device.

Evaporator and Condenser Principles

Unit Objective

Upon completion of this unit, you will be able to explain the principles of various evaporator/condenser configurations.

Discussion Outline

The Discussion of Fundamentals covers the following points:

- New terms and words
- Equipment required

Discussion of Fundamentals

The flow of heat energy is always from a point of higher temperature to a point of lower temperature (hot to cold). This can be observed by heating one end of a metal bar and measuring temperature points along the bar. The temperature of the cold end of the bar will slowly increase. Therefore, heat energy flows from a high temperature to a low temperature. This flow continues as the speed of the molecules at the cold end increases with the absorption of heat. An equilibrium point is eventually reached where all molecules have the same average **kinetic energy** (energy of motion) and therefore, the same temperature. This method of heat transfer is known as **conduction**.

It is by conduction that heat is transferred from the refrigerated compartment into the evaporator coils, and from the condenser coils into the surrounding air.

Since copper is a good conductor of heat, it is used when constructing evaporators, condensers, and the associated tubing lines. As the refrigerant travels through these devices, heat transfer occurs between the refrigerant and copper tubing. The direction of heat transfer is dependent on the stage of the refrigeration cycle.

The efficiency of a refrigeration system can be increased after considering the relative directions of heat flow at various stages of the refrigeration cycle. Consider that heat is flowing outward from the hot condenser line to the surrounding air, while heat is flowing inward from the surrounding air to the cool suction line. By thermally connecting these two lines together, heat transfer can take place from the condenser line to the suction line. This is known as **superheating** and **subcooling**. The following exercises will provide detailed explanations of the principles involved and reasons why this is advantageous to the operation of a refrigeration system.

New terms and words

Conduction – a method by which heat energy is transferred by actual collision of the molecules within the heated material.

Counter-flow – flow of refrigerant in opposite directions.

Heat exchanger – a device used in many refrigeration systems to increase the overall efficiency of the system by sub-cooling the liquid line and superheating the suction line.

Kinetic energy – the energy responsible for the motion of molecules.

Minimum Stable Signal (MSS) point – the point at which the temperature of the thermal bulb of the thermostatic expansion valve changes the least when the system is running.

Saturation – the condition which exists when the space occupied by the refrigerant is holding as much of the vapor as it can at a particular temperature.

Subcooling – the removal of sensible heat from the liquid refrigerant before it passes through the metering device.

Superheating – the heating of the refrigerant vapor beyond the amount required to maintain its boiling temperature.

Equipment required

- Refrigeration System Trainer, Model 3401

Exercise 6-1

Superheating and Subcooling

EXERCISE OBJECTIVE When you have completed this exercise, you will be able to demonstrate the principles of superheating and subcooling as they relate to refrigeration systems.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Superheating
- Subcooling
- Superheat in a TEV
- Measuring the Superheat
- Charging Systems for Superheat

DISCUSSION

Superheating

In refrigeration systems, the suction line is the tubing which runs from the evaporator into the compressor. This line returns the heat-laden refrigerant vapor from the evaporator to the compressor. The line is arranged so that the refrigerant vapor is warmed a few degrees as it absorbs heat through the walls of the tubing. Heat that is absorbed in this manner is known as superheat.

Superheat refers to the heat contained in the refrigerant vapor, beyond the amount required to maintain its boiling temperature. This type of heat is considered sensible heat since it causes a rise in temperature.

By superheating the refrigerant in the suction line, it can be ensured that no liquid flows back into the compressor, which could cause damage to equipment.

Subcooling

To increase the efficiency of some refrigeration systems, the liquid refrigerant is cooled before it passes through the metering device. This is accomplished by removing sensible heat from the liquid through the walls of the tubing. The procedure is known as subcooling.

One method of subcooling is to run the liquid line and the suction line together such that heat is transferred between the lines. Subcooling occurs since the refrigerant vapor in the liquid line is considerably cooler than the refrigerant in the liquid line. This method also serves to superheat the cool refrigerant in the suction line in order to ensure that no liquid refrigerant enters the compressor.

Superheat in a TEV

A vapor is superheated whenever the vapor temperature is higher than the saturation temperature corresponding to the vapor pressure. When dealing with thermostatic expansion valves, superheat refers to the difference in temperature between the liquid refrigerant at the evaporator inlet and the refrigerant vapor at the expansion valve sensing bulb near the evaporator outlet. A system with the thermostatic expansion valve adjusted to operate at a normal 5.6°C (10°F) superheat is shown in Figure 6-1.

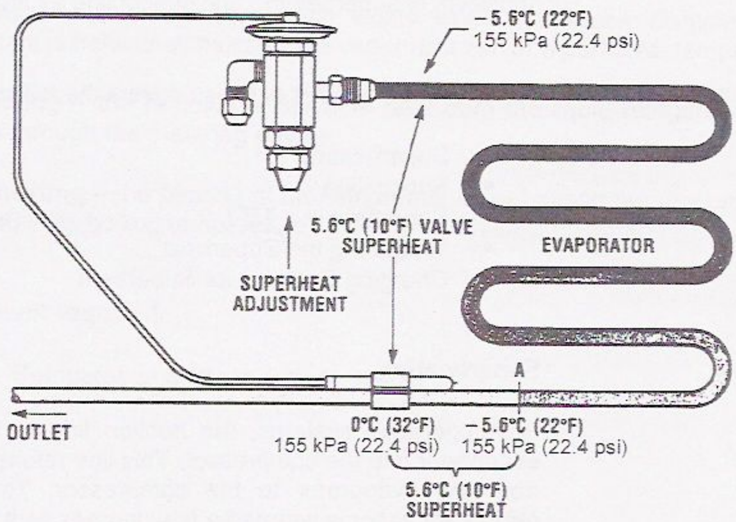


Figure 6-1. A thermostatic expansion valve adjusted to give a normal 5.6°C (10°F) superheat.

In this system, liquid refrigerant at a temperature of −5.6°C (22°F) exits the thermostatic expansion valve. The liquid refrigerant flows through the evaporator, absorbing heat with no change in refrigerant temperature. However, the liquid refrigerant changes completely to refrigerant vapor by the time it reaches point A, through the latent heat of vaporization. Heat which continues to be absorbed by the refrigerant vapor after point A is called sensible heat. As sensible heat is absorbed from the cooling compartment by the refrigerant, the refrigerant temperature is increased by 5.6°C (10°F), thus reaching a temperature of 0°C (32°F) at the sensing bulb. The 5.6°C (10°F) difference in temperature between the evaporator inlet and the outlet, with no change in pressure, is called superheat. The degree to which the refrigerant vapor is superheated depends on the amount of refrigerant being fed to the evaporator by the TEV and the heat load to which the evaporator is exposed.

When the operating superheat is raised unnecessarily high, the evaporator capacity decreases, since more of the evaporator surface is required to produce the superheat necessary to operate the expansion valve. Only part of the evaporator is filled with liquid refrigerant and less latent heat is being absorbed by vaporizing liquid refrigerant. This is called "starving" the evaporator. Thus, it is important to adjust the expansion valve to operate at the minimum possible superheat setting that ensures all refrigerant is vaporized before leaving the evaporator.

A "starved" evaporator will also result when a pressure drop through the evaporator is experienced. Figure 6-2 shows an evaporator experiencing a 24 kPa (3.4 psi) pressure drop, corresponding to a 2.7°C (5°F) temperature drop. This pressure drop occurs by the time the refrigerant reaches point B.

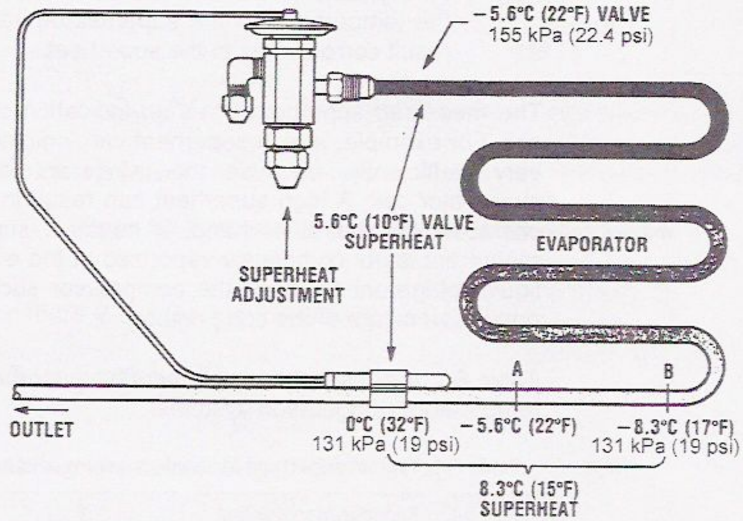


Figure 6-2. Starved evaporator.

Since the expansion valve spring is set at a compression equivalent to 5.6̊C (10°F) superheat, it is required that the evaporator outlet temperature be 0°C (32°F) for the valve to be in equilibrium. Due to the pressure drop, the pressure at this point is only 131 kPa (19 psi) and the corresponding saturation temperature is −8.3°C (17°F). Thus, a superheat of 8.3°C (15°F) is required to open the valve. This increase in superheat, from 5.6°C (10°F) to 8.3°C (15°F), makes it necessary to use more of the evaporator surface to produce this higher superheated refrigerant gas. All liquid refrigerant must be vaporized before reaching point B and enough sensible heat must be absorbed between point B and the thermal bulb to produce an 8.3°C (15°F) superheat. Therefore, the amount of evaporator surface available for absorption of latent heat of vaporization of the refrigerant is reduced and the evaporator is starved before the required superheat is reached.

The type of refrigerant control and adjustment affects the amount of superheat in the suction line. When the system is running, the best superheat setting for an evaporator is the point at which the temperature of the thermal bulb of the thermostatic expansion valve changes the least. This setting is called the **Minimum Stable Signal (MSS) point** or setting. This setting is a result of the evaporator flow behavior and the behavior of the thermostatic expansion valve.

Measuring the Superheat

The superheat of the vapor is usually measured by using the steps below:

- First, measure the pressure of the superheated vapor at the evaporator outlet (that is, where the sensing bulb of the thermostatic expansion valve is located);

- Then, find the saturation temperature corresponding to the measured pressure on the pressure-temperature (P/T) chart of the refrigerant used (see Appendix F of this manual);
- Finally, calculate the difference between the saturation temperature and the temperature of the superheated vapor at the evaporator outlet. The result corresponds to the superheat.

The measured superheat gives an indication of the efficiency of the evaporator coil. For example, a high superheat can indicate that the evaporator is operating very inefficiently, because the refrigerant is vaporizing too quickly in the evaporator coil. A high superheat can result in poor heat transfer in the cooling chamber. On the other hand, a negative superheat value indicates that the refrigerant is not completely vaporized at the evaporator outlet, which can cause liquid refrigerant to reach the compressor suction inlet, and in turn can cause premature failure of the compressor.

Table 6-1 indicates the recommended superheat for high-, medium-, and low-temperature refrigeration systems.

Table 6-1. Typical superheat for high-, medium, and low-temperature refrigeration systems.

Refrigeration system	Recommended superheat
High-temperature [-1.1°C (30°F) and above in the evaporator]	Between 5.5 and 6.6°C (10 and 12°F) approximately
Medium-temperature [between -16 and -1.1°C (0 and 30°F) in the evaporator]	Between 2.8 and 5.5°C (5 and 10°F) approximately
Low-temperature [below -16°C (0°F) in the evaporator)]	Between 1.1 and 2.8°C (2 and 5°F) approximately

Charging Systems for Superheat

In refrigeration systems using a liquid receiver and thermostatic expansion valve, the refrigerant charge applied to the system may vary slightly. However, on refrigeration systems using a capillary tube or thermostatic expansion valve with no liquid receiver, the refrigerant charge must be precise. The refrigerant charge in the system ensures an appropriate superheat setting for maximum system efficiency.

It is desirable to keep liquid refrigerant flowing along most of the evaporator to maximize evaporator efficiency, but precautions must be taken to prevent any liquid from entering the compressor suction line. By taking a superheat measurement at the suction line and adjusting the system to have a minimum amount of superheat, this condition can be readily obtained.

A schematic diagram of a typical refrigeration system is shown in Figure 6-3. This system will be used to examine superheat when using a thermostatic expansion valve.

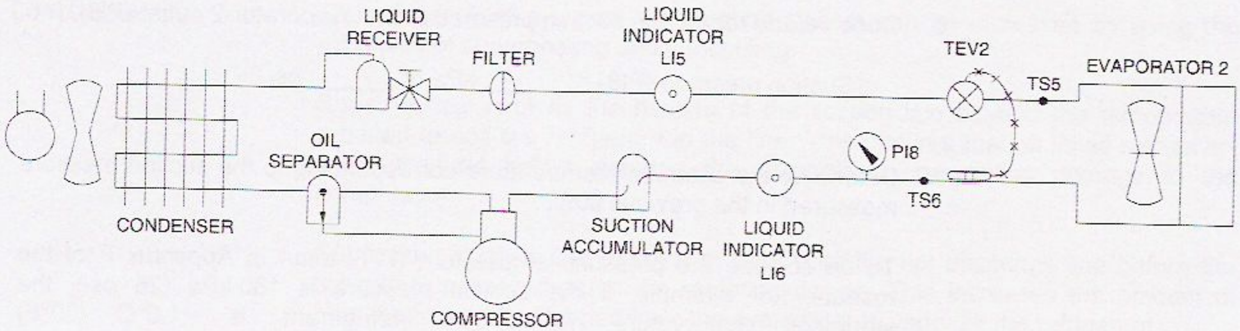


Figure 6-3. Schematic diagram of typical refrigeration system.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Superheating and subcooling

PROCEDURE

Superheating and subcooling

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 6-3. Figure A-8 in Appendix A may be used to assist in the proper set-up of the system.

   Place the evaporator cabinet divider (located at the top of the two evaporator cabinets) in the up position in order to isolate evaporator 1 from evaporator 2.

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______

3. Turn on the mains input breaker switch.

4. Set the speed of the condenser fan to medium. Set the speed of the evaporator-2 fan to maximum.

5. Start up the compressor and operate the trainer for approximately 10 minutes. This allows the system to stabilize before any readings are taken.

6. Observe and record the suction pressure at the evaporator-2 outlet (PI8).

   Suction pressure (PI8) = ______ kPa or ______ psi

7. Determine the saturation temperature corresponding to the suction pressure measured in the previous step.

   To do so, use the pressure-temperature (P/T) chart in Appendix F of the manual. For example, if the suction pressure is 180 kPa (26 psi), the saturation temperature, for R-134a refrigerant, is −1.0°C (30°F) approximately.

   Saturation temperature = ______°C or ______°F

8. Measure the mean temperature of the suction line refrigerant vapor at the thermal bulb location on evaporator 2 (TS6).

   Mean suction line temperature (TS6) = ______ °C or ______ °F

9. Calculate and record the superheat at evaporator 2 by subtracting the saturation temperature recorded in procedure step 7 from the mean suction line temperature recorded in procedure step 8.

   Superheat = ______ °C or ______ °F

   The superheat setting should be between 4.4°C (8°F) and 5.6°C (10°F) approximately.

10. If the measured superheat is different than the typical superheat specified, advise your instructor.

    The pressure-superheat troubleshooting chart in Appendix E provides probable causes and solutions for typical faults encountered in refrigeration systems. The most probable cause is that thermostatic expansion valve TEV1 requires a readjustment. This valve may be adjusted for proper superheat setting by adjusting the spring tension screw on the bottom of the valve. To adjust the thermostatic expansion valve, remove the cap on the bottom of the valve to expose the adjusting stem. Adjust the valve setting to provide the proper superheat. Clockwise adjustment of the stem decreases the refrigerant flow through the valve and increases the superheat. Counterclockwise adjustment increases refrigerant flow through the valve and lowers superheat.

11. Turn off the condenser and evaporator fans.

12. Turn off the compressor and main breaker switch.

CONCLUSION

The efficiency of a typical refrigeration system can be increased by using the principles of superheating and subcooling.

Superheating involves the heating of the suction line beyond the temperature required to boil the refrigerant in the line. This ensures that all liquid refrigerant has vaporized before entering the compressor, preventing damage to the compressor.

Subcooling involves the removal of heat from the hot discharge line before the refrigerant passes through the metering device. This increases the amount of heat that must be extracted from the evaporator to vaporize the refrigerant.

One method of achieving both subcooling and superheating at the same time is to thermally connect the suction line to the discharge line. Thus, heat is removed from the hot discharge line and added to the cool suction line.

REVIEW QUESTIONS

1. Define superheat.

   the temperature in a refrigerant beyond its boiling capacity

2. What is the advantage of superheating the suction line of a refrigeration system?

   It allows almost no liquid refrigerant to return to the compressor.

3. Describe subcooling and explain why it is advantageous in a refrigeration system.

   supercooling is when liquid refrigerant temperature is cooled down by transfering heat through the walls of the tubing. This helps increase efficiency.

4. How can both subcooling and superheating be accomplished? Describe the flow of heat energy in this configuration.

   superheat and subcooling can be achieved by running both the suction and liquid line together. Heat will flow from the liquid to suction line (high -> low) thus decreasing liquid line temp AND increasing suction temperature.

5. Describe the effects on the evaporator when a thermostatic expansion valve has too high a superheat setting.

When the superheat is too high the evaporator will become "starved", which will decrease the evaporator capacity since only part of the evaporator receives liquid refrigerant.

Exercise 6-2

Heat Exchanger

EXERCISE OBJECTIVE When you have completed this exercise, you will be able to demonstrate the operation of a heat exchanger as used in refrigeration systems.

DISCUSSION OUTLINE The Discussion of this exercise covers the following points:

- Introduction

DISCUSSION

Introduction

The efficiency of a refrigeration system can be increased if the refrigerant liquid is subcooled before it reaches the refrigerant control. This means the refrigerant must be cooled more than its condensed temperature before entering the metering device. The increase in refrigeration resulting from the subcooling of the refrigerant is equal to the difference between the initial liquid temperature and the subcooled liquid temperature.

A heat exchanger, as shown in Figure 6-4, is a device used in many commercial refrigeration systems to increase the overall efficiency of the system. The heat exchanger subcools the refrigerant before it enters the metering device and heats the refrigerant before it enters the compressor. This ensures all the liquid refrigerant entering the compressor turns to a vapor.

Figure 6-4. Heat exchanger.

A heat exchanger consists of a coil of tubing wrapped around a section of the suction line tubing such that they are in good thermal contact with each other, as shown in Figure 6-5.

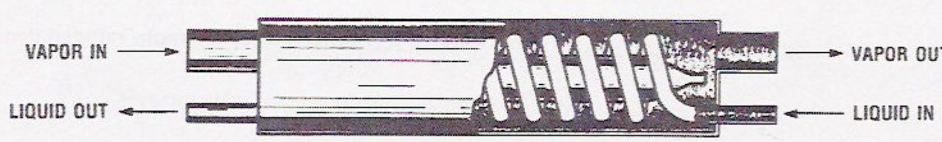


Figure 6-5. Cross-sectional diagram of a heat exchanger.

When refrigerant leaves the condenser, it is at a high pressure and temperature. Cold suction vapor is piped through the heat exchanger in a **counter-flow** direction to the warm liquid refrigerant flowing through the liquid line to the

refrigerant control. As the cold suction vapor flows through the heat exchanger, heat is absorbed from the warm liquid. This results in the liquid refrigerant being subcooled before reaching the metering device, as the refrigerant vapor in the suction line is superheated. Since the heat absorbed by the vapor, when superheated, is drawn from the liquid, the heat of the liquid is reduced by an amount equal to the amount of heat absorbed by the vapor.

When a heat exchanger is used, the heat given up by the liquid, when it is subcooled, is absorbed by the suction vapor and therefore remains in the system.

Heat exchangers increase the efficiency of a refrigeration system by preventing the vaporizing of refrigerant vapor as its pressure is reduced by the metering device. Also, by reducing the liquid refrigerant temperature, the refrigerant will have a greater capacity to absorb heat in the evaporator, increasing the efficiency of the system.

On a standard refrigeration system, the refrigerant leaves the condenser in a saturated state. Therefore, as soon as the refrigerant pressure is reduced in the metering device, liquid refrigerant changes into a vapor. This is commonly known as "flash vapor".

Since the vapor occupies a much greater volume than it did as a liquid, refrigerant flow through the metering device is partially restricted. However, by installing a heat exchanger in the system, the liquid refrigerant is cooled to a few degrees below saturation. Therefore, the refrigerant must first warm up to its saturation point before it can vaporize. The refrigerant now flows through the metering device and vaporizes in the evaporator. This results in free liquid flow through the metering device which also increases system efficiency.

A schematic diagram of a refrigeration system using a capillary tube control is shown in Figure 6-6. This system will be used to show the effects of adding a heat exchanger into the refrigeration system.

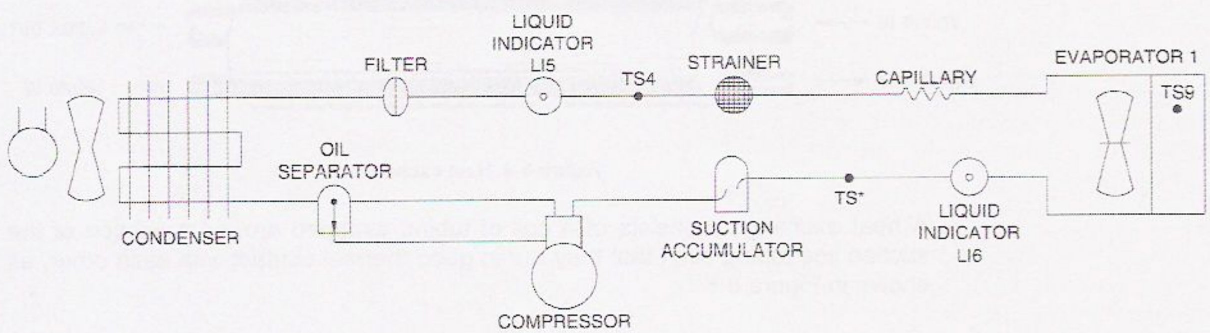


Figure 6-6. Schematic diagram of a refrigeration system.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Heat exchangers

PROCEDURE

Heat exchangers

1. Open and close the manual valves to arrange the refrigeration system as shown in Figure 6-6. Figure A-9 in Appendix A may be used to assist in the proper set-up of the system.

   Place the evaporator cabinet divider in the up position in order to isolate evaporator 1 from evaporator 2.

2. Record which valves are open and closed.

OPEN VALVES			CLOSED VALVES		
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______
______	______	______	______	______	______

3. Turn on the mains input breaker switch.

4. Set the condenser fan speed to medium. Set the evaporator-1 fan speed to medium.

5. Start up the compressor and operate the trainer for approximately 10 minutes. This allows the system to stabilize before any readings are taken.

6. Measure and record the following temperature and pressure readings.

   Capillary tube inlet temperature (TS4) = ______ °C or ______ °F

   Evaporator-1 cabinet temperature (TS9) = ______ °C or ______ °F

   Heat exchanger outlet temperature
   (TS* : between LI6 and valve V23) = ______ °C or ______ °F

   Compressor suction pressure (PI2) = ______ kPa or ______ psi

   Compressor discharge pressure (PI1) = ______ kPa or ______ psi

7. Observe the liquid indicator LI6. Is liquid present in the line?

   ____

8. Open valve V7 and close valve V8. Allow the system to operate for approximately 10 minutes. This will allow it to stabilize.

9. Measure and record the temperature at the capillary tube inlet (TS4). Does this reading differ from that recorded in procedure step 6? Explain.

   ____

   ____

   ____

   ____

   ____

   ____

10. Measure and record the temperature at the heat exchanger outlet (TS*: between LI6 and valve V23). Does this reading differ from that recorded in procedure step 6? Explain.

    ____

    ____

    ____

11. Measure and record the temperature in the evaporator-1 cabinet (TS9). Does this reading differ from that recorded in procedure step 6? Explain.

    ____

    ____

    ____

12. Observe the liquid indicator LI6. Is liquid present in the suction line? Explain.

    ____

    ____

    ____

13. Note and record the compressor suction and discharge pressures (PI2 and PI1).

    Compressor suction pressure (PI2) = ______ kPa or ______ psi

    Compressor discharge pressure (PI1) = ______ kPa or ______ psi

    You should observe that the pressure differential (PI1 – PI2) across the compressor has decreased with the addition of the heat exchanger, while the cabinet temperature has remained constant. This demonstrates an increase in the efficiency of the refrigeration system. Is this what you observed? Explain.

    ____

    ____

    ____

14. Turn off the evaporator and condenser fans.

15. Turn off the compressor and main breaker switch.

CONCLUSION

A heat exchanger is a device used in many commercial refrigeration systems to improve refrigeration efficiency. Liquid refrigerant is subcooled before entering the metering device. Refrigerant in the suction line is also superheated to ensure that all refrigerant is vaporized before entering the compressor.

The amount of heat removed from the liquid line is equal to the amount of heat absorbed by the suction line when passed through the heat exchanger. Thus, the increased efficiency of the evaporator is equal to the amount of heat energy removed from the liquid line. With this heat removed, more heat must be extracted from the evaporator to raise the temperature of the refrigerant.

The heat exchanger consists of a coiled length of tubing wrapped tightly around a section of the suction line, in good thermal contact, to facilitate heat transfer between the two lines.

REVIEW QUESTIONS

1. What is the function of a heat exchanger in refrigeration systems?

   ____

   ____

   ____

2. Describe the physical structure of a typical heat exchanger.

   ____

   ____

   ____

3. Explain the principles of operation of a heat exchanger.

4. What is flash vapor?

5. What is the advantage of having the suction line absorb the heat from the liquid line?

Unit Test

1. Heat transfer in a refrigeration system occurs mainly by

   a. radiation.
   b. conduction.
   c. convection.
   d. None of the above is correct.

2. Heat contained in the refrigerant vapor beyond the amount required to maintain its boiling temperature is called

   a. subcooling.
   b. superheat.
   c. latent heat.
   d. None of the above is correct.

3. When a heat exchanger is used in a refrigeration system, the refrigerant in the liquid line becomes

   a. subcooled.
   b. superheated.
   c. vaporized.
   d. condensed.

4. Superheating ensures that all refrigerant is completely

   a. liquefied.
   b. solidified.
   c. vaporized.
   d. cooled.

5. Evaporator superheat is measured as the temperature difference between the

   a. evaporator inlet and compressor inlet.
   b. condenser inlet and condenser outlet.
   c. thermostatic expansion valve inlet and thermal bulb.
   d. evaporator inlet and expansion valve thermal bulb.

6. An expansion valve with too high a superheat setting will cause the evaporator to be

   a. less efficient.
   b. lower capacity.
   c. starved.
   d. All of the above are correct.

7. Typical superheat settings for medium-temperature refrigeration systems

   a. 2.8 - 8.3°C (5 - 15°F)
   b. 5.6 - 11.2°C (10 - 20°F)
   c. 2.8 - 5.6°C (5 - 10°F)
   d. 8.3 - 11.2°C (15 - 20°F)

8. The superheat of a refrigeration system is influenced by

   a. expansion valve setting.
   b. refrigerant charge level.
   c. evaporator capacity.
   d. All of the above are correct.

9. The point at which the temperature of the thermal bulb of the thermostatic expansion valve changes the least, when the system is running, is called

   a. vaporization point.
   b. boiling point.
   c. minimum stable signal point.
   d. maximum stable signal point.

10. A refrigeration system with proper superheat setting, will have a redundant component when the system contains a

    a. liquid receiver.
    b. filter.
    c. thermostatic controller.
    d. suction accumulator.

7. Typical superheat settings for medium-temperature refrigeration systems

   a. 2.8 - 8.3°C (5 - 15°F)
   b. 5.6 - 11.2°C (10 - 20°F)
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